89th Congress }
1st Session }

COMMITTEE PRINT

MINERAL AND WATER RESOURCES OF NEW MEXICO

REPORT

PREPARED BY THE

UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

THE

NEW MEXICO STATE ENGINEER OFFICE

AND THE

NEW MEXICO OIL CONSERVATION COMMISSION

AT THE REQUEST OF

SENATOR CLINTON P. ANDERSON
OF NEW MEXICO

OF THE

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS
UNITED STATES SENATE

Printed for the use of the Committee on Interior and Insular Affairs

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COMMITTEE ON INTERIOR AND INSULAR AFFAIRS

MEMORANDUM FROM THE CHAIRMAN

To Members of the Senate Committee on Interior and Insular Affairs:

I am transmitting for your information a report entitled "Mineral and Water Resources of New Mexico," prepared by the U.S. Geological Survey at the request of our colleague, Senator Clinton P. Anderson.

This detailed survey will be particularly helpful to government and business leaders in New Mexico. It will also be valuable to the Congress and members of this committee as we consider legislation regarding mineral and water development.

HENRY M. JACKSON, *Chairman.*

FOREWORD

This report was prepared at my request by the U.S. Geological Survey in collaboration with the New Mexico Bureau of Mines and Mineral Resources, the New Mexico State Engineer Office and the New Mexico Oil Conservation Commission.

Its purpose is to make all significant data on New Mexico's important mineral and water resources available to interested citizens, to professional personnel in mining and water development, and to government, civic, and industrial leaders. I think that purpose has been well met.

I wish to thank all of those both in New Mexico and the Geological Survey who have contributed to the making of this report.

CLINTON P. ANDERSON.

MINERAL AND WATER RESOURCES OF NEW MEXICO

REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

THE

NEW MEXICO STATE ENGINEER OFFICE

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LETTER OF TRANSMITTAL

U.S. DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington, D.C., January 13, 1965.

Hon. CLINTON P. ANDERSON,
U.S. Senate,
Washington, D.C.

DEAR SENATOR ANDERSON: We have forwarded to your office a summary report on the mineral and water resources of New Mexico, which was prepared in response to your request of July 8, 1964, to the Geological Survey.

The report was prepared by the Geological Survey in collaboration with the New Mexico Bureau of Mines and Mineral Resources, the New Mexico Oil Conservation Commission, and the New Mexico Engineer Office. We enjoyed extremely close support from the different collaborating State agencies and are grateful for their assistance.

We hope the report will provide information of use to you and to the people of New Mexico in general.

Sincerely yours,

STEWART L. UDALL,
Secretary of the Interior.

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ILLUSTRATIONS

INTRODUCTION

(By G. O. Bachman, U.S. Geological Survey, Denver, Colo.)

This report summarizes the mineral and water resources of New Mexico. The use, manner of occurrence, distribution, and outlook for all known mineral commodities in the State are discussed in separate chapters. Where available, statistics on the production of mineral commodities are summarized. In an introductory section the mineral industry and the geology of the State are outlined briefly.

The purpose of this report is to present an objective appraisal of the resources of New Mexico based on information now available, although new discoveries and changes in economic conditions may alter some of the conclusions reached. Treatment of each commodity is necessarily brief but comprehensive bibliographies are included for the convenience of those who may wish to inquire further into the mineral and water resources of New Mexico.

In this report the term "resources" applies to materials in the ground that are known to be minable; materials that may come into demand and become minable in the future; and water. "Reserves" are materials that may or may not be completely explored but may be quantitatively estimated and are considered to be economically exploitable at the time of the estimate. Reserves fluctuate because they are dependent on economic conditions, technologic factors, and available information. A low reserve figure does not necessarily mean that the resource is near exhaustion. It may indicate exploration is lacking or that a depressed market has lowered the value of the commodity to the point where the material can no longer be considered economically exploitable. "Ore" is mineral material that may be mined at a profit. "Protore," used in some parts of this report, is a mineral material that may not be mined at a profit under present economic or technologic conditions.

This report was compiled by members of the U.S. Geological Survey in cooperation with other Federal and State agencies. Members of the staff of the New Mexico Institute of Mining and Technology, State Bureau of Mines and Mineral Resources, contributed chapters to the report and cooperated in the search for data. Staff members of the New Mexico Oil Conservation Commission contributed discussions and statistics on the petroleum industry in the State. The New Mexico State Engineer Office cooperated in preparation of the section on water resources. Some chapters in this report have been prepared by personnel of the U.S. Bureau of Mines. Mr. George O. Bachman, U.S. Geological Survey, assembled the various sections of the report and coordinated efforts of the individual authors. Unless otherwise stated, statistical data used in the report have been compiled by Margaret Dunbar of the Bureau of Mines and Ruth Wilson of the Geological Survey under the direction of D. H. Mullen, U.S. Bureau of Mines, Mineral Resources Office (Statistics).

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MINERAL INDUSTRY IN NEW MEXICO

(By G. O. Bachman, U.S. Geological Survey, Denver, Colo.)

In 1962 New Mexico ranked seventh among all the States in annual production of mineral resources and first among the States of the Rocky Mountain region. During this year New Mexico contributed 3.58 percent of the total domestic minerals produced in the country. The mineral resources that contributed chiefly to this wealth are petroleum, natural gas and related products, uranium, potassium salts, and copper. New Mexico ranks sixth among the Nation's oil- and gas-producing States, first in production of uranium and potassium salts, and third in the production of copper.

The total value of mineral resources produced in New Mexico for the 58-year period 1905 through 1963, for which accurate records are available, is $9,083.8 million. To this total may be added an estimate of $26.7 million in mineral production from the earliest mining to 1904 (Jones, 1904, p. 345) thus making a grand total of $9,110.5 million for all known mineral production in New Mexico through 1963. About 88 percent of this amount, or $8,158.7 million, has been produced since 1940. Figure 1 shows the annual dollar value[1] of mineral production from 1905 to 1963 and illustrates the growth of the industry in the State. Figure 2 shows the percentages of the principal mineral commodities produced in New Mexico in 1963 whose value totaled $686.8 million.

Geographically, the greatest mineral wealth produced in New Mexico during 1963 came from the San Juan Basin in the northwestern part of the State and the Delaware basin in the southeastern part. The combined value of crude petroleum, natural gas, uranium, and coal from the San Juan Basin, and crude petroleum, natural gas, and potash salts from the Delaware basin was about $599 million. The next most significant production figure was that of the southwestern part of the State where the production of copper and associated minerals was valued at about $59 million. The value of other mineral commodities produced throughout the State during 1963 was over $28 million.

The search for minerals of economic value in the area that is now New Mexico began more than 400 years ago. Rumors of mineral wealth resulted in the first major exploratory expedition in New Mexico in 1540. That expedition, under the command of Francisco Vasquez de Coronado, returned disappointed to Mexico in 1542; but it was followed by other explorers, missionaries, adventurers, and finally by settlers in search of permanent homes.

Records of development of mineral resources during the colonial period from the late 16th to the early 19th centuries are meager. Twitchell (1916, vol. I, p. 1, 2) listed an archive pertaining to the registration of a mine "in the little mountain called Fray Cristobal"

[1] Dollar value is the amount in dollars reported for the year of production.

in 1685. Twitchell stated that this mine was "probably situated west of the present town of Engle, Sierra County, N. Mex." The mine was probably not worked as it was registered during the period of the Pueblo Revolt. Numerous registrations of other mines during the Colonial period are recorded. Vaguely worded registrations of

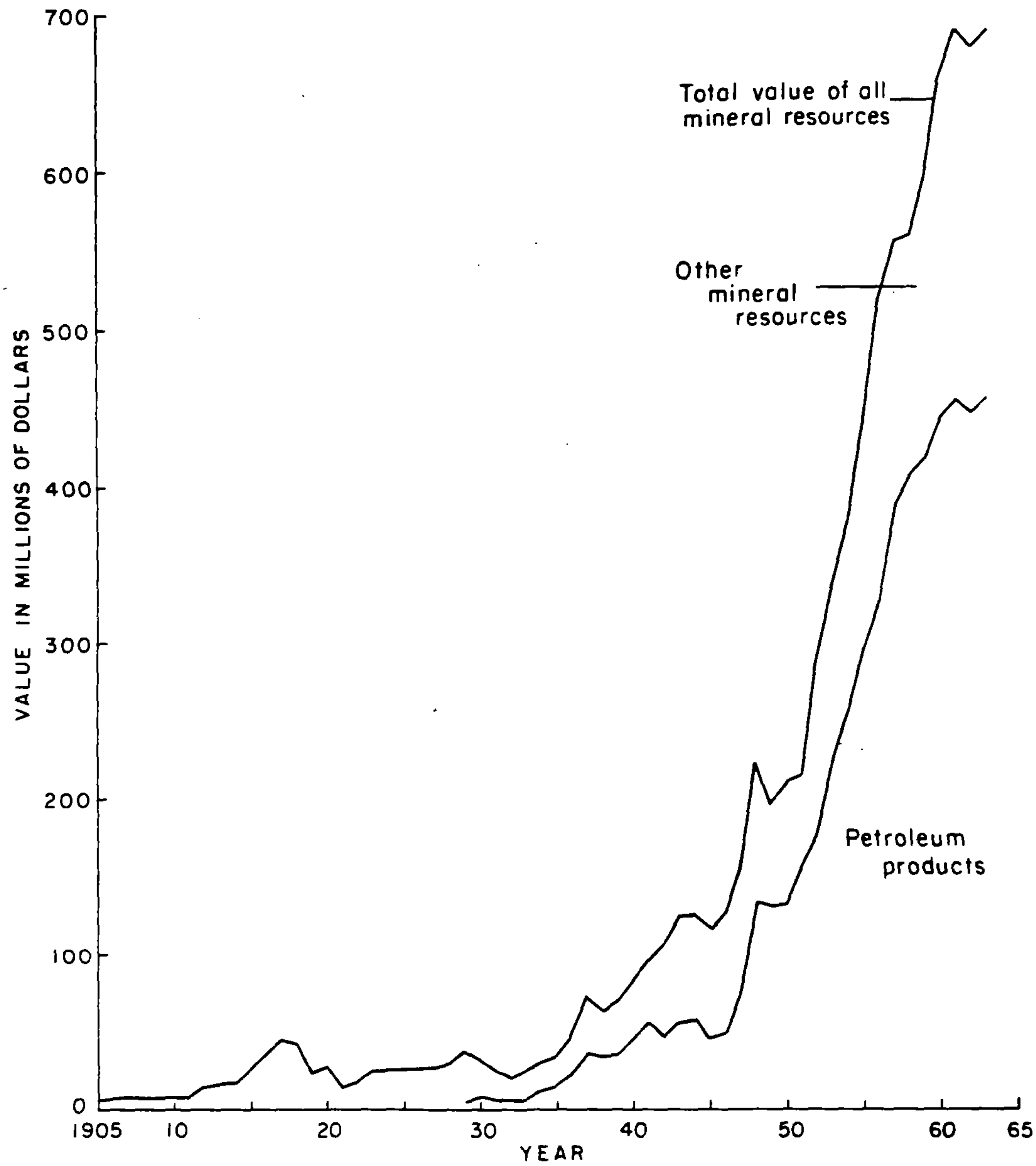


FIGURE 1.—Value of mineral resources produced in New Mexico, 1905–63.

mines as well as misinterpretations of some colonial reports have resulted in a colorful literature of rich, "lost" Spanish mines.

Some prospecting was reported done in the area that is now New Mexico in the 17th and 18th centuries, but there is little evidence of extensive mining in New Mexico during Spanish colonial time. The Spanish word *mina*, as used in colonial reports and documents, may be translated as "mineral occurrences" and "prospects" as well as "mines." Northrup (1959, p. 12) has pointed out that the more optimistic translation of the term *mina* to mean "mines" may have stimulated the search for these "mines" and thus may have been responsible for the discovery of valuable mineral deposits by later prospectors.

Some small-scale mining in Santa Fe County was carried out in the 17th century. Salt deposits in the Estancia Valley, Torrance County, were developed in the 17th and 18th centuries. This salt was

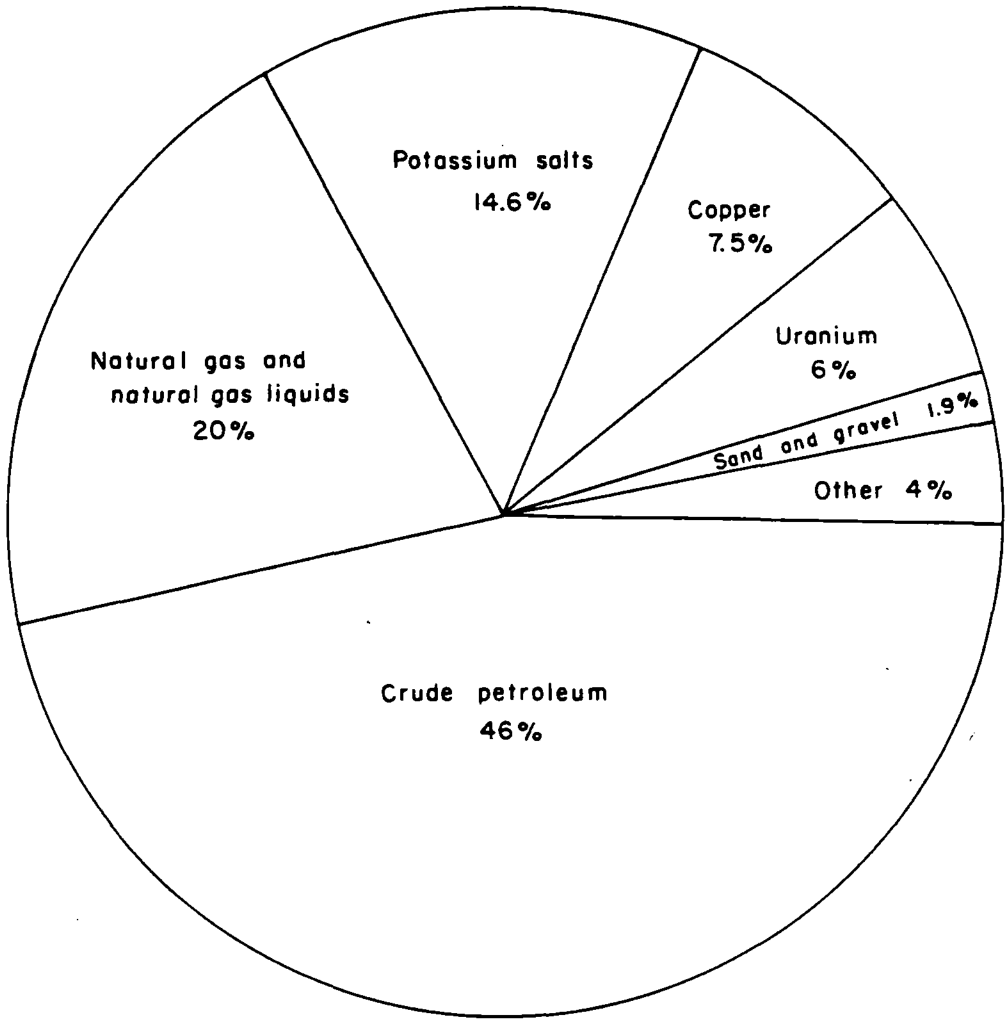


FIGURE 2.—Percentage of total mineral resource production in New Mexico, 1963.

carried by wagons and pack animals to the silver mines in Parral, Mexico, where it was used in the primitive "patio" metallurgical process for the extraction of silver from ore. Mica was used for window panes. The first major mine was opened in the area that is now New Mexico in about 1804 near the present Santa Rita mine, Grant County.

Extensive prospecting was conducted in the State in the late 19th century and it was during this period that most of the major mining districts in New Mexico were discovered. Major deposits of uranium, however, were not discovered until after 1948 when the demand for uranium that developed during and after World War II was the incentive for prospecting for this metal.

Although the State was prospected extensively during the late 19th and early 20th centuries, new tools that are now available to the modern prospector have essentially reopened the field to further work that could lead to major new discoveries. The science of geophysics with its newly developed instruments for use in the air and on the ground has become much more sophisticated and highly specialized. Geochemical prospecting is a rapidly developing and practical field technique for the detection of small, but of anomalous amounts of metals in soil, water, and plants. Isotope chemistry and physics, X-ray and spectroscopic analysis, highly sensitive chemical techniques, and other refined laboratory methods make possible the more accurate identification and quantitative determination of trace amounts of elements that may give clues to the location of undiscovered ore deposits.

The future of mineral resources production is dependent on continuing demand, discovery, exploration, and development. As indicated in numerous chapters in this report, development of many of New Mexico's resources is increasing. With the increased use of coal in the production of electricity, the coal industry will probably continue to expand. On the other hand, the future of the uranium industry is less predictable at present. Uranium production will be regulated by government purchases through 1970. Beyond 1970 the production of uranium will depend on industrial demand or continued government purchase. The growing demand for silver and other metals, along with new uses for many minerals by modern technology, indicates that exploration for these resources will increase.

Of all the natural resources of a state or a nation, none is probably more important than water, but also, none is more difficult to evaluate in terms of dollars and cents. It is significant to note that New Mexico occupies a unique and pioneering position in the use of its water resources. As stated by McGuinness (1963, p. 558), New Mexico was among the earliest States "to be explored and settled, and hydrologically too it was among the pioneers. The U.S. Geological Survey learned how to measure streamflow at an experimental camp set up at Embudo, on the Rio Grande halfway between Santa Fe and the Colorado line, late in 1888 after the Congress appropriated money for an irrigation survey of the arid lands and thus added water resources investigations to the Survey's responsibilities (Dutton, 1890, pp. 78–79). Some of the classical work of Slichter (1905 a, b) on estimation of ground water flow was done in the Rio Grande valley in New Mexico and Texas, in the vicinity of El Paso. The Survey's investigation, in cooperation with the State Engineer and Chaves and Eddy Counties, of the ground water resources of the Roswell artesian basin (Fiedler and Nye, 1933) was one of the pioneer quantitative ground water studies. It led directly to enactment of the New Mexico ground water law of 1927 and 1931, which was the earliest of its kind and has served as a model for similar laws in several other States (National Resources Planning Board, 1943, pp. 76, 123, 133–134; Hutchins, 1955b, p. 47). The Rio Grande Joint Investigation * * * was the first interstate planning study of its type."

The study of the water resources of the State is a continuous process. Streamflow data are collected at 193 sites. Reservoirs are monitored at 16 sites. Daily chemical-quality records are maintained for 17 sites and daily suspended sediment samples are collected at 21 sites. In addition to this work, local and regional water resource studies are in progress.

TOPOGRAPHY AND GEOLOGY

(By C. H. Dane, U.S. Geological Survey, Washington, D.C., and G. O. Bachman, U.S. Geological Survey, Denver, Colo.)

TOPOGRAPHY

New Mexico is the fifth largest State in the Union, including an area of 121,666 square miles of extraordinary diverse terrain, both topographically and geologically. The total topographic relief within the State boundaries is more than 10,000 feet. The highest point, Wheeler Peak, 30 miles south of the Colorado border in the Sangre de Cristo Mountains, reaches an altitude of 13,160 feet; the lowest point, Red Bluff Reservoir on the Pecos River along the southern boundary of the State, lies somewhat less than 3,000 feet above sea level. By far the largest part of the area of the State, however, lies at altitudes of between 5,000 and 10,000 feet above sea level. Between one-quarter and one-third lies below 5,000 feet, principally east of a diagonal line extending irregularly northeastward from the vicinity of Carlsbad to the Oklahoma boundary in the northeast corner. Other large areas below 5,000 feet include the valley of the Rio Grande from the southern boundary north to a short distance north of Albuquerque, the Jornada del Muerto and Tularosa Valley, and some thousands of square miles of similarly aggraded plains in the southwestern part of the State.

About 1,000 square miles of area rise above the 10,000-foot contour. This includes chiefly peaks in the Southern Rocky Mountains in the north-central part of the State, particularly in the Sangre de Cristo, Cimarron, San Juan, Jemez, and San Pedro Mountains. Smaller areas of more than 10,000 feet altitude occur on Mount Taylor, the Sandia and Manzano Mountains in the central part of the State, and on the Magdalena, San Mateo, Capitan, and Mogollon Mountains and the Black Range and Sierra Blanca in the southern part (fig. 3).

Topographically the State can be divided into three principal divisions, the Great Plains province of about the eastern one-third, the Intermontane Plateaus comprising most of the remainder, and the Southern Rocky Mountains including a relatively small portion of the north-central part (fig. 4). The boundaries between these divisions and between the subdivisions of those to be described are transitional and in places necessarily somewhat arbitrary. They do, however, represent distinctive terrains that are related to the bedrock geology and to the geologic history of the State.

The Great Plains Province includes: (*a*) the High Plains, extensive, smooth, high level, fluviatile plains, only slightly dissected in any area within the State, (*b*) the Pecos Valley, late mature to old plains, somewhat younger and at lower levels than the High Plains, and (*c*) the Raton Section, a considerably more varied area than the others, but in general a trenched or deeply eroded peneplain surmounted by dissected lava-capped plateaus and buttes. The Intermontane Plateaus of the western part of the State have been divided

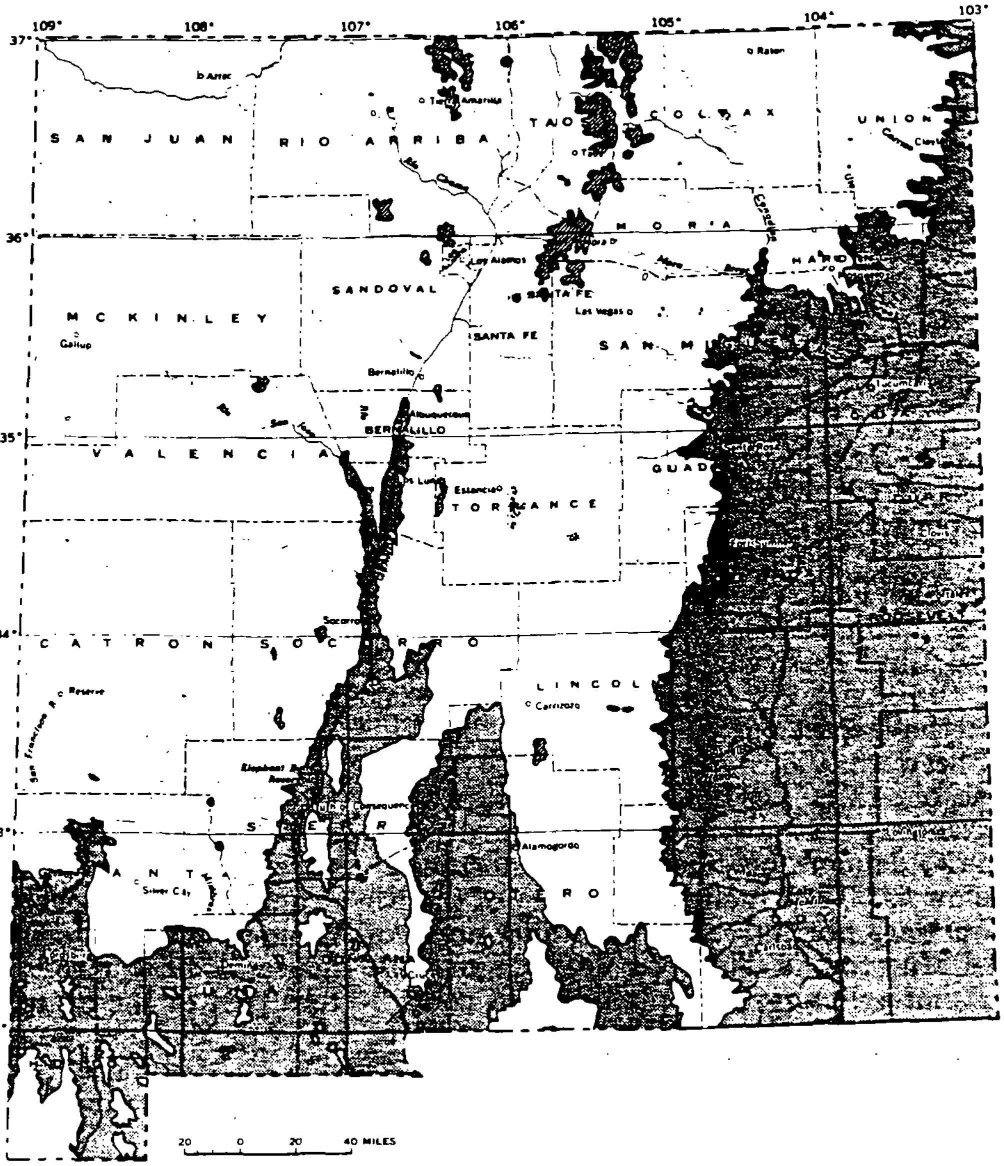


FIGURE 3.—Generalized relief map of New Mexico. Line pattern shows areas above 10,000 feet in altitude; gray, areas below 5,000 feet in altitude.

into two provinces, the Colorado Plateaus in the northwest and the Basin and Range Province in the southwest and central part of the State. The Colorado Plateaus include the Navajo section of the Canyon lands, chiefly young but canyoned plateaus of moderate relief and the Datil section to the south, including laval flows, complete or in extensive remnants, volcanic necks, and other extrusive and intrusive rock masses. The Basin and Range Province also includes two sections within New Mexico, the Mexican Highland, including isolated ranges (largely dissected block mountains) separated by aggraded desert plains and the Sacramento section, mature block mountains of gently tilted strata, block plateaus and bolsons.

The Southern Rocky Mountains Province includes only a relatively small part of the State along its northern border and is generally considered as terminating to the south at the southern end of the Sangre de Cristo Range and the Nacimiento Mountains. Nevertheless, the generally meridional trend of these mountains is continued southward to the southern border by a succession of ranges of not greatly dissimilar geologic features. These ranges include the Sandia, Manzano, and Los Pinos Mountains; the Fra Cristobal and Caballo Mountains;

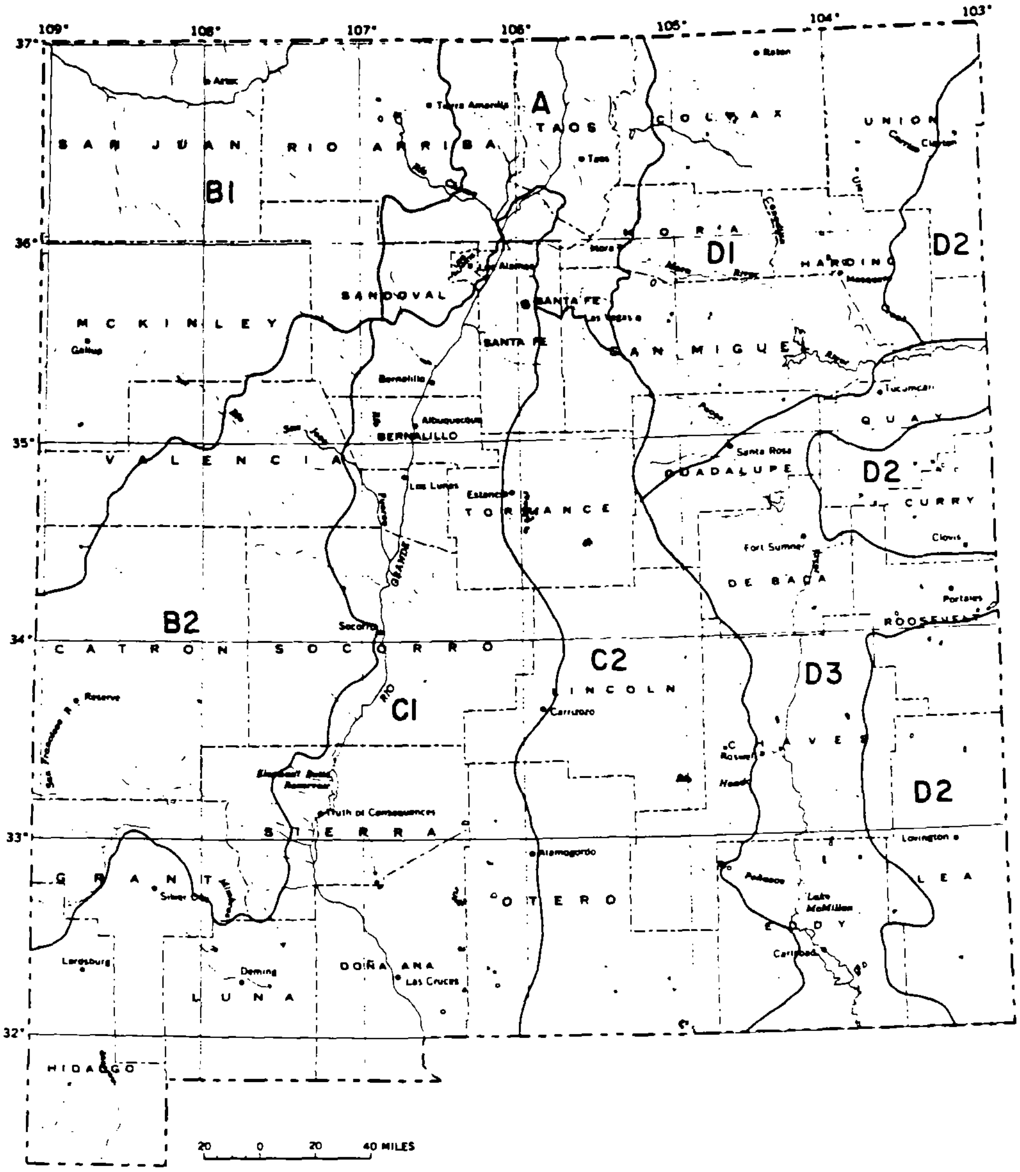


FIGURE 4.—Physical divisions of New Mexico. (A, Southern Rocky Mountains; B1, Colorado Plateaus, Navajo section; B2, Colorado Plateaus, Datil section; C1, Basin and Range province, Mexican highland; C2, Basin and Range province, Sacramento section; D1, Great Plains province, Raton section; D2, Great Plains province, High Plains; D3, Great Plains province, Pecos Valley. (Fenneman, 1962.)

the Oscura, San Andres, Organ, and Franklin Mountains; and Sierra Blanca and the Sacramento Mountains (fig. 5). These ranges, though separated by much wider deeply alluviated valleys, in the aggregate form a belt 50 to 100 miles wide from east to west that extends from the northern to the southern boundary of the State and in a broad way divides the plateau, lava, and canyon lands in the western part of the State from the plains and areas of generally lower topographic relief of the eastern part.

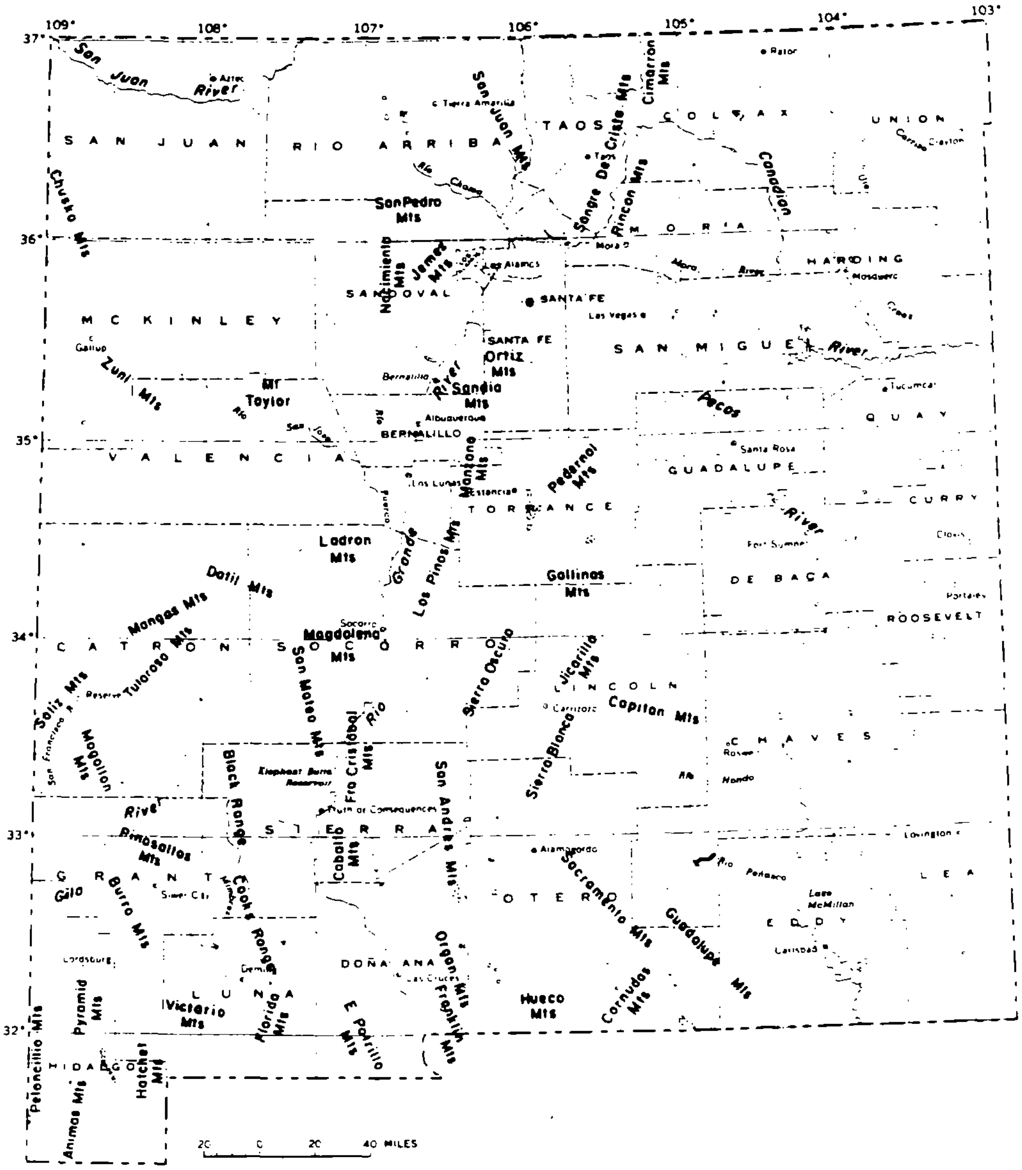
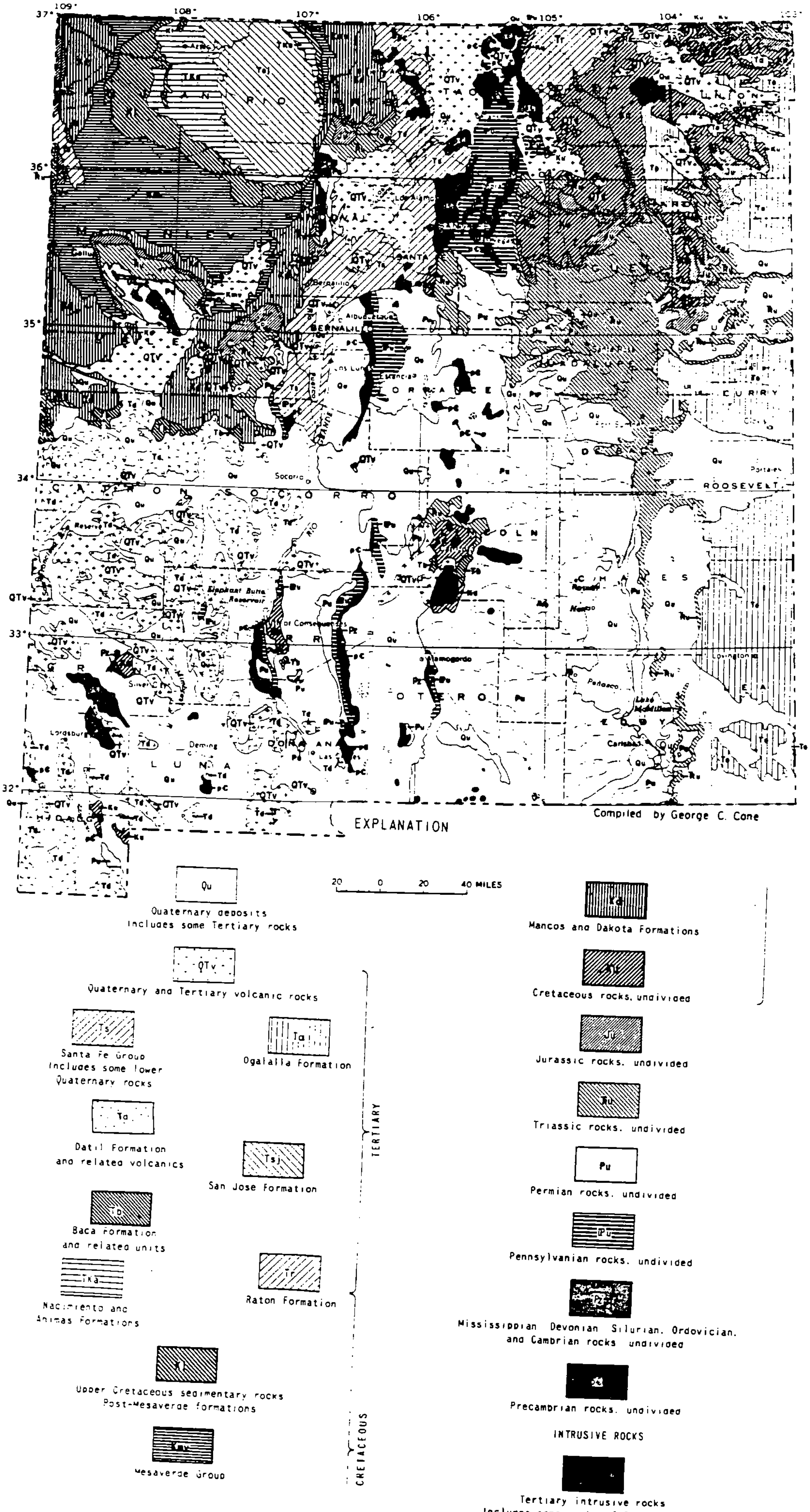


FIGURE 5.—Index map showing location of principal mountain ranges and rivers in New Mexico.

GEOLOGY

The rocks exposed in the ranges, mesas, and plateaus and concealed beneath the alluviated plains and desert basins record a long and infinitely varied geologic history. At times nearly all the State was submerged beneath shallow seas. At other times much of the State stood above the level of the sea and the previously formed rocks were eroded and transported to other areas. During some ages great deserts of wind-blown sand swept across the State; and, at other times, areas marginal to extensive seas were vast evaporting pans in which thick deposits of gypsum or other salts crystallized from the concentrated

41-737 O - 65 (Face p. 22)



F.GURE 5.—Geologic map of New Mexico. Generalized from geologic map of New Mexico by Carle H. Dane and George O. Bachman, U.S. Geological Survey (in press.)

brines. At still other times river and flood-plain deposits ranging from great boulders and coarse gravel, to fine sand, and to clay were strewn thickly over wide surfaces above the level of the sea, and extensive swamps bordering the seas accumulated thick beds of decaying plant detritus that subsequently were compressed and modified into coal. At times too, molten rock from the depths of the earth forced its way into the already consolidated sedimentary rocks, or burst through to the earth's surface as volcanos, which distributed windblown ash or emitted great sheets of lava. Many of these widely varied rocks contain mineral resources of economic value. The distribution and value of mineral resources are understood most adequately through a fuller understanding of the geologic processes that created them. The rocks that record the history of these processes are briefly described in the following pages. The generalized geologic map (fig. 6) shows the distribution of some of these rocks as they are exposed on the surface today.

Rocks of every geologic system into which strata have been classified in the United States crop out within New Mexico and are extensively distributed in the subsurface, where they have been encountered by the thousands of wells that have been drilled for oil or gas (tables 1–4). The rocks belonging to all but the oldest category are dominantly, though not exclusively, sedimentary rocks. That is, they were deposited as sediments by rivers, wind, or ocean currents and subsequently consolidated into bedded layers of rock. Much of this volume of sedimentary rock is distinguished by the presence, in greater or lesser amounts, of organisms of varied kinds, the fossil remains of past life, by means of which the containing rocks can be recognized, correlated from place to place, and placed in order of relative age by their superposition in orderly sequences.

Precambrian Rocks

The oldest rocks in New Mexico are classified simply as Precambrian. Fossils are not present in these rocks and they can be subdivided only on the basis of rock type or absolute age. In some areas these rocks have been studied in detail; but, as they have not been studied regionally over the State, only generalizations may be made about their age and relationships.

Precambrian rocks form the floor on which subsequent sequences of rocks were deposited. These foundation rocks are commonly referred to as "basement rocks" or simply as "the basement". Many of these very old rocks have been intensely deformed and altered. Some have been recrystallized into new combinations of minerals or metamorphosed in other ways. Precambrian rocks in New Mexico now consist of quartzite, schist, gneiss, granite, and many other rock types.

Precambrian rocks crop out only in a small fraction of the area of the State, most extensively in the higher parts of the Sangre de Cristo, Cimarron, San Juan, and Nacimiento Mountains in the north-central part of the State. They also are present in considerable areas of the uplifted cores of meridional ranges that transect the State from south to north, and in many smaller areas, some only a few acres in extent, scattered throughout the southwestern part of the State. Precambrian rocks do not crop out east of a diagonal line extending northeastward

TABLE 1.—*Nomenclature of principal formations in northwestern New Mexico*

Era	Geologic time units		Formations	
Cenozoic (to 70 million years	Quaternary	Recent	Alluvium	
		Pleistocene	Gravel, sand, clay and volcanic deposits	
	Tertiary	Pliocene	Santa Fe Group	Chuska Sandstone
		Miocene		
		Oligocene	May be present (?)	
		Eocene	Galisteo Formation (Eocene and questionably Oligocene); Baca Formation (questionably Eocene); San Jose Formation	
		Paleocene	Nacimiento Formation; Animas Formation (Upper Cretaceous and Paleocene)	
Mesozoic (70-225 million years _/)	Cretaceous		Ojo Alamo Sandstone McDermott Formation Kirtland Shale and Fruitland Formation Pictured Cliffs Sandstone Lewis Shale	
			Cliff House Sandstone Menefee Formation Point Lookout Sandstone Crevasse Canyon Formation Gallup Sandstone	All of the Mesaverde Group
			Mancos Shale Dakota Sandstone	
	Jurassic		San Rafael Group: Morrison Formation Bluff Sandstone Summerville Formation Todilto Formation Entrada Sandstone	Zuni Sandstone
	Triassic		Glen Canyon Group Wingate Sandstone Chinle Formation	
Paleozoic (225 to 600 million years _/)	Permian		San Andres Limestone Glorieta Sandstone	
			Yeso Formation Abo Formation	Cutler Formation Rico Formation
	Carboniferous	Pennsylvanian	Madera Formation Sandia Formation	Hermosa Formation Paradox Member Molas Formation
		Mississippian	Arroyo Penasco Formation	Present in subsurface (includes the Leadville Limestone)
	Devonian		Present in subsurface	Ouray Limestone Includes the Elbert Formation
	Silurian		Absent	
	Ordovician		Absent	
	Cambrian		Present in subsurface	Includes the Ignacio Quartzite
Precambrian (3 billion years _/.)			Granite, quartzite, pegmatites, etc.	

TABLE 2.—*Nomenclature of principal formations in northeastern New Mexico*

Era	Period	Geologic time units	Formations	
Cenozoic (to 70 million years)	Quaternary	Recent	Alluvium, other surficial deposits, and some volcanic deposits	
		Pleistocene	Gravel, sand, caliche and some volcanic deposits	
	Tertiary	Pliocene	Santa Fe Group	Ogallala Formation
		Miocene		
		Oligocene (?) Eocene	Galisteo Formation and other local formations	
		Paleocene	Poison Canyon Formation Raton Formation	
Mesozoic (70-225 million years_/)		Cretaceous	Vermejo Formation Trinidad Sandstone Pierre Shale Niobrara Formation Carlile Shale Greenhorn Limestone Graneros Shale Dakota Sandstone Purgatoire Formation	
		Jurassic	Morrison Formation Summerville Formation Todilto Limestone Entrada Sandstone	
		Triassic	Dockum Group Chinle Formation Santa Rosa Sandstone	
(225 to 600 million years_/)		Permian	Artesia Formation San Andres Limestone Glorieta Sandstone Yeso Formation	
		Permian and Pennsylvanian	Sangre de Cristo	
	Carboniferous	Pennsylvanian	Madera Limestone Sandia Formation	
		Mississippian	Tererro Formation	
		Devonian	Espiritu Santo Formation	
		Silurian	Absent	
		Ordovician	Absent	
		Cambrian	Absent	
Precambrian (3 billion years_/.			Granite, diorite, other plutonic rocks, schist, quartzite, and pegmatites.	

TABLE 3.—*Nomenclature of principal formations in southwestern New Mexico*

<table>
<tr><th colspan="3">Geologic time units</th><th colspan="3">Formations</th></tr>
<tr><td rowspan="8">Cenozoic (to 70 million years)</td><td rowspan="3">Quaternary</td><td>Recent</td><td colspan="3">Alluvium, other surficial deposits and volcanic rocks</td></tr>
<tr><td rowspan="2">Pleistocene</td><td colspan="3">Gravel and volcanic rocks</td></tr>
<tr><td rowspan="3">Santa Fe Group</td><td>Gila Conglomerate</td><td rowspan="3">Datil Formation and associated volcanic rocks</td></tr>
<tr><td rowspan="5">Tertiary</td><td>Pliocene</td><td rowspan="2"></td></tr>
<tr><td>Miocene</td></tr>
<tr><td>Oligocene</td><td colspan="3">May be present (?)</td></tr>
<tr><td>Eocene</td><td colspan="3">Baca Formation of questionable Eocene age</td></tr>
<tr><td>Paleocene</td><td colspan="3">Not recognized (?)</td></tr>
<tr><td rowspan="5">Mesozoic (70-225 million years_/</td><td colspan="2" rowspan="3">Cretaceous</td><td>Mesaverde Group</td><td colspan="2">Includes some volcanic rocks</td></tr>
<tr><td>Mancos Shale
Dakota Sandstone</td><td colspan="2">Colorado Shale
Sarten Sandstone & Beartooth Quartzite</td></tr>
<tr><td colspan="3">Bisbee Group:
Includes a sequence of conglomerate, sandstone, volcanic rocks, etc. more than 10,000 feet thick in extreme southwestern New Mexico.</td></tr>
<tr><td colspan="2">Jurassic</td><td colspan="3">Absent</td></tr>
<tr><td colspan="2">Triassic</td><td colspan="3">Present in northern part of region</td></tr>
<tr><td rowspan="7">Paleozoic (225 to 600 million years_/)</td><td colspan="2">Permian</td><td>Concha Formation
Scherrer Formation
Colina Limestone
Earp Formation</td><td colspan="2">San Andres Limestone
Glorieta Sandstone
Yeso Formation
Abo Formation
Bursum Formation</td></tr>
<tr><td rowspan="2">Carboniferous</td><td>Pennsylvanian</td><td colspan="3">Horquilla Formation -- Magdalena Group</td></tr>
<tr><td>Mississippian</td><td>Lake Valley Limestone
Kelly Limestone</td><td colspan="2">Escabrosa Limestone</td></tr>
<tr><td colspan="2">Devonian</td><td colspan="3">Percha Shale (and other local formations)</td></tr>
<tr><td colspan="2">Silurian</td><td colspan="3">Fusselman Dolomite</td></tr>
<tr><td colspan="2">Ordovician</td><td colspan="3">Montoya Dolomite
El Paso Formation</td></tr>
<tr><td colspan="5">Ordovician and Cambrian Bliss Sandstone</td></tr>
</table>

Precambrian (3 billion years_/). Granite and associated rocks.

TABLE 4.—Nomenclature of principal formations in southeastern New Mexico.

Geologic time units			Formations	
Cenozoic (to 70 million years)	Quaternary	Recent	Alluvium and other surficial deposits	
	Quaternary	Pleistocene	Gravel and associated deposits	
	Quaternary	Pliocene	Ogallala Formation	
	Tertiary	Miocene	Probably present (?)	
	Tertiary	Oligocene	Not recognized	
	Tertiary	Eocene	Not recognized (?)	
	Tertiary	Paleocene	Not recognized (?)	
Mesozoic (70-225 million years)	Cretaceous		Mesaverde Group Mancos Shale Dakota Sandstone (?)	
	Jurassic		Absent	
	Triassic		Dockum Group	
Paleozoic (225 to 600 million years_/)	Permian		Dewey Lake Redbeds Rustler Formation Salado Formation Castile Formation	
	Permian		All of the Artesia Group	Tansill Formation Yates Formation Seven Rivers Formation Queen Formation Grayburg Formation
	Permian		San Andres Limestone includes the Hondo Sandstone Member Glorieta Sandstone Yeso Formation Abo Formation Bursum Formation	Cutoff Shale Victorio Peak Limestone Bone Spring Limestone Hueco Limestone
	Carboniferous	Pennsylvanian	Includes many formations and informally named zones in the subsurface	
	Carboniferous	Mississippian	Lake Valley Limestone and other local formations	"Mississippian Lime" of subsurface
	Devonian		Percha Shale	Woodford Shale of subsurface
	Silurian		Fusselman Dolomite	"Devonian" of subsurface
	Ordovician		Montoya Dolomite	
	Ordovician		Simpson Formation of subsurface	
	Ordovician		El Paso Formation	Ellenburger Formation of subsurface
	Ordovician and Cambrian		Bliss Sandstone	
Precambrian (3 billion years_/.			Granite and associated rocks.	

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from El Paso, Tex., to Raton, nor in the San Juan Basin in the northwestern part, nor in the central part of the Datil volcanic area of the southwest part of the State.

The exposed Precambrian rocks do not show a distinctive general pattern of distribution. Somewhat more of a pattern is displayed by the distribution of these rocks where encountered in drilled wells. Although more than 500 wells have reached Precambrian rocks, more than 200 of these are in eastern Lea County. The distribution of the remainder is sparse in many parts of the State. Nevertheless, these wells show that granite underlies much of the northeastern part of the State, the southeastern part of the San Juan Basin, most of the south-central and southwestern parts of the State, and large areas in Lea and Eddy Counties in the southeastern part.

Although the relative ages of the Precambrian rocks of the State are not well understood, it appears that the most deeply metamorphosed rocks are the oldest (about 1,110 to 1,300 million years) and that they are followed in age successively by intrusive granite and granitoid rocks, by relatively unmetamorphosed sedimentary rocks associated with intrusive and extrusive rhyolites, and by a younger group of granitic intrusive rocks. The increased amount of radiometric dating of the Precambrian rocks that will become available in the future will greatly clarify our understanding of the correlations and history of these rocks.

PALEOZOIC ROCKS

The Paleozoic Era is represented in New Mexico by a succession of sedimentary rocks which is divided into systems and local formations (tables 1–4). The older Paleozoic rocks are divided into Cambrian, Ordovician, and Silurian Systems. Rocks of these ages consist mainly of limestone and dolomite, and include some sandstone. They were deposited in shallow seas that oscillated across the land. Deposition was discontinuous and environments of deposition were variable. These factors have resulted in distinctive rock types in each system and the rock types may be divided into mappable formations.

During Late Cambrian and Early Ordovician time the Bliss Sandstone and El Paso Limestone were deposited in a sea that probably transgressed across the land from the west. Rocks correlated with the Middle Ordovician Simpson Group of Oklahoma are present in the subsurface in southeastern New Mexico and in Middle and Late Ordovician time the Montoya Dolomite was deposited in a continuous seaway across southern New Mexico. In Silurian time the Fusselman Dolomite was deposited in a sea that may have encroached on the land from the east. The seas were probably relatively warm and, during parts of early Paleozoic time, were hosts to many species of primitive corals, bivalves, crinoids, and other forms of animal life.

Rocks of the early part of the Paleozoic Era are preserved only in the southern and northwestern parts of New Mexico. Although these rocks may be as much as 2,500 feet thick in the south-central part of the State, they are eroded and generally absent north of the latitude of the Caballo and Fra Cristobal Mountains in Socorro County, and north of the Oscura Mountains in Lincoln County. They are well exposed in the Sacramento Mountains, Otero County, but are absent north of Alamagordo. They have been encountered in wells drilled in the Delaware basin in southeastern New Mexico. The Ignacio Quartzite of Late Cambrian age has been encountered in wells in the northwestern part of New Mexico.

Younger Paleozoic rocks are included in the Devonian, Mississippian, Pennsylvanian, and Permian Systems. Rocks of these ages include limestone, dolomite, gypsum and anhydrite, salt, potash minerals, shale, sandstone, and conglomerate. They reflect changing environments of deposition.

The Devonian rocks, largely represented by the Percha Shale in southern New Mexico are relatively thin but form a widespread blanket of dark, calcareous to sandy shale. Devonian rocks have much the same distribution in New Mexico as the earlier Paleozoic rocks, but they are probably also present at places in the Sangre de Cristo Mountains.

Mississippian rocks consist mainly of limestone and are present over much of southern New Mexico as well as places in the Sangre de Cristo, Nacimiento, and Sandia Mountains. They are also present in the subsurface in northwestern part of the State. The Mississippian rocks, which have a maximum thickness exceeding 1,200 feet in southwestern New Mexico, have been assigned to a large number of locally recognized stratigraphic units.

Pennsylvanian and Permian rocks were deposited in widely variable environments including the flanks of mountains that rose out of the sea, shallow seas, enclosed basins, and salt pans. The rocks, therefore, are of great variety and have been assigned to numerous stratigraphic units. Pennsylvanian rocks include gypsum, limestone, sandstone, and conglomerate. Permian formations include those rock types as well as much dolomite and, in southeastern New Mexico, thick salt and potash deposits. In parts of southeastern New Mexico Pennsylvanian and Permian rocks may exceed 12,000 feet in thickness.

All the Paleozoic rocks are presently being studied intensively by geologists, for it is from these rocks that much of the petroleum is being produced in New Mexico. An understanding of regional variations in rock types, position of ancient shore lines and mountain uplifts, and environments of deposition are necessary to predict the occurrence of petroleum. In addition, the understanding of ancient uplifts and fracturing of rocks is important in the study of ore deposits. Because of this intensive study, numerous formation names have been proposed for rocks in New Mexico. These names are not listed here because of the complexity of nomenclature. The accompanying tables (tables 1–4) are intended to serve only as generalized outlines for reference.

Mesozoic Rocks

Deposits of Mesozoic age include rocks of the Triassic, Jurassic, and Cretaceous Systems. At the close of Paleozoic time seas withdrew from New Mexico and lower Mesozoic rocks are of continental origin. Triassic rocks in New Mexico are usually red to maroon and include shale and sandstone deposited on floodplains or in other subaerial environments. Triassic rocks are preserved in northern and eastern New Mexico. They are exposed in southeastern New Mexico along the Pecos River nearly to the State line. The maximum thickness of Triassic rocks may exceed 2,000 feet along the eastern edge of the State.

Jurassic rocks include a complex sequence of nonmarine units, largely clastic, of eolian, stream, and lacustrine origin. They are exposed widely in northern New Mexico around the edges of the San Juan Basin where they locally exceed 1,000 feet in thickness, in mountain uplifts, and in deeply cut canyons including those of the Canadian and Cimarron Rivers. Jurassic rocks are not present in New Mexico south of an easterly line across the south-central part of the State.

During Cretaceous time seas again advanced over New Mexico and rocks were deposited in, or marginal to, a marine environment. The main body of the Cretaceous sea lay to the east of New Mexico and extended from the Arctic to the Gulf of Mexico. In southwestern New Mexico, however, the lowest Cretaceous rocks accumulated to thicknesses of more than 15,000 feet in a deep trough centered in the area of the Little Hatchet Mountains. Upper Cretaceous rocks were deposited over northern New Mexico in lagoons, along beaches, and in offshore and marine environments. Complex intertonguing relations record the oscillatory advance of the sea and differences in the rate of supply of sediment. The rocks consist of shale and sandstone with some beds of limestone and local coal beds.

The oldest formation in the Upper Cretaceous sequence is the widespread Dakota Sandstone. Overlying the Dakota in northwestern New Mexico is the Mancos Shale which was deposited as a marine mud. The Mesaverde Group consists of several formations that interfinger with the underlying Mancos Shale and record deposition of sand, silt, clay, and plant debris in streams and swamps. Almost the entire history of Upper Cretaceous deposition over much of New Mexico is marked by repeated advances of the sea with the drowning of rivers and swamps followed by retreat of seas and renewal of river systems and swamp environments. The well preserved record of these events in New Mexico has long intrigued geologists and the study of these rocks and their history has resulted in classic concepts of sedimentation, facies changes, and interfingering of strata.

Cenozoic Rocks

At the close of Cretaceous time, seas withdrew from the New Mexico region; and regional uplift of the land, accompanied by mountain building, began. Therefore, there are no known marine deposits in New Mexico that are younger than Cretaceous age. Tertiary rocks consist of clay, shale, sandstone, volcanic flows, and igneous intrusions. Some coal beds were deposited in the Raton Basin during early Tertiary time.

During the earliest part of Tertiary time, sediments were deposited in the San Juan and in the Raton Basins. The Tertiary rocks in the San Juan Basin include gray shale, variegated red, purple, and white shale, sandstone, and brown conglomerate. Rocks in the San Juan Basin were probably deposited on the surface of floodplains that contained some areas of a heavily wooded savanna environment. In the Raton basin lower Tertiary rocks consist of coal, gray shale, and interbedded conglomerate sandstone beds that interfinger and grade into the overlying conglomerates. These rocks were deposited in a swamp and floodplain environment that was covered later by a piedmont terrane.

Other sedimentary formations were deposited in intermontane basins in Tertiary and early Quarternary time. These include the Galisteo Formation of Eocene and Oligocene(?) age in southern Santa Fe County, the Baca Formation of Eocene(?) age in central New Mexico, and the Santa Fe Group of Miocene to Pleistocene(?) age in the vicinity of the Rio Grande Valley. The Santa Fe Group consists of clay, sand, gravel, and some interbedded volcanic rocks. The Santa Fe Group is best exposed in northern Santa Fe County but it may be present along much of the course of the Rio Grande in New Mexico. The Pliocene and Pleistocene Gila Conglomerate in southwestern New Mexico is very similar lithologically to the Santa Fe Group.

In southwestern New Mexico there was extensive volcanic activity and local igneous intrusions during Tertiary time. The Datil Formation, chiefly of Tertiary age, formed a volcanic field that covers much of Catron, Grant, and western Socorro and Sierra Counties. Some volcanic rocks in Hidalgo, Luna, and Dona Ana Counties may be related to the Datil volcanic episode.

Rocks of Quaternary age in New Mexico include sedimentary and igneous deposits. The sedimentary deposits include caliche, alluvium and valley fill, clay, sand, and gravel. The igneous rocks include volcanic flows and ash falls of varied composition.

The sedimentary rocks are chiefly the result of weathering and breakdown of mountain masses. Products of weathering have been carried by streams into valleys where they are deposited. Most Quaternary sedimentary deposits are unconsolidated and friable but in some areas chemical processes in nature are operative and well-cemented spring deposits (travertine) are in the process of formation. In some enclosed basins, as in the Estancia Basin in eastern Valencia County and the Tularosa Basin in western Otero County, saline deposits have accumulated during relatively recent time. These deposits are the result of saline-bearing water that evaporates into the atmosphere leaving saline crystals as deposits on or near the surface of the ground. Dunes of the White Sands in Otero County are composed of small grains of gypsum that have been fragmented in the atmosphere and moved and rounded by wind action.

During Pleistocene time, commonly known as the "Ice Age," glaciers were not as widespread in New Mexico as in the northern part of the United States. Mountain glaciers formed in parts of the Sangre de Cristo Mountains and as far south as Sierra Blanca Peak in Lincoln County, but ice did not cover New Mexico in sheets. During the time of glaciation the climate in New Mexico was probably much wetter and colder than present climate. About 12,000 to 13,000 years ago man was hunting the mammoth and other large animals in the area that is now New Mexico. Average summer temperature in the Estancia Valley in Torrance County was 10° to 12° lower than at present and the annual precipitation was probably 8 inches more than present precipitation. During the past 6,000 years, climate has been variable with a tendency towards relatively warm and more arid conditions. The variable climate of recent time is reflected by several cycles of arroyo cutting and filling in the drainage systems of New Mexico.

Geologic Structure

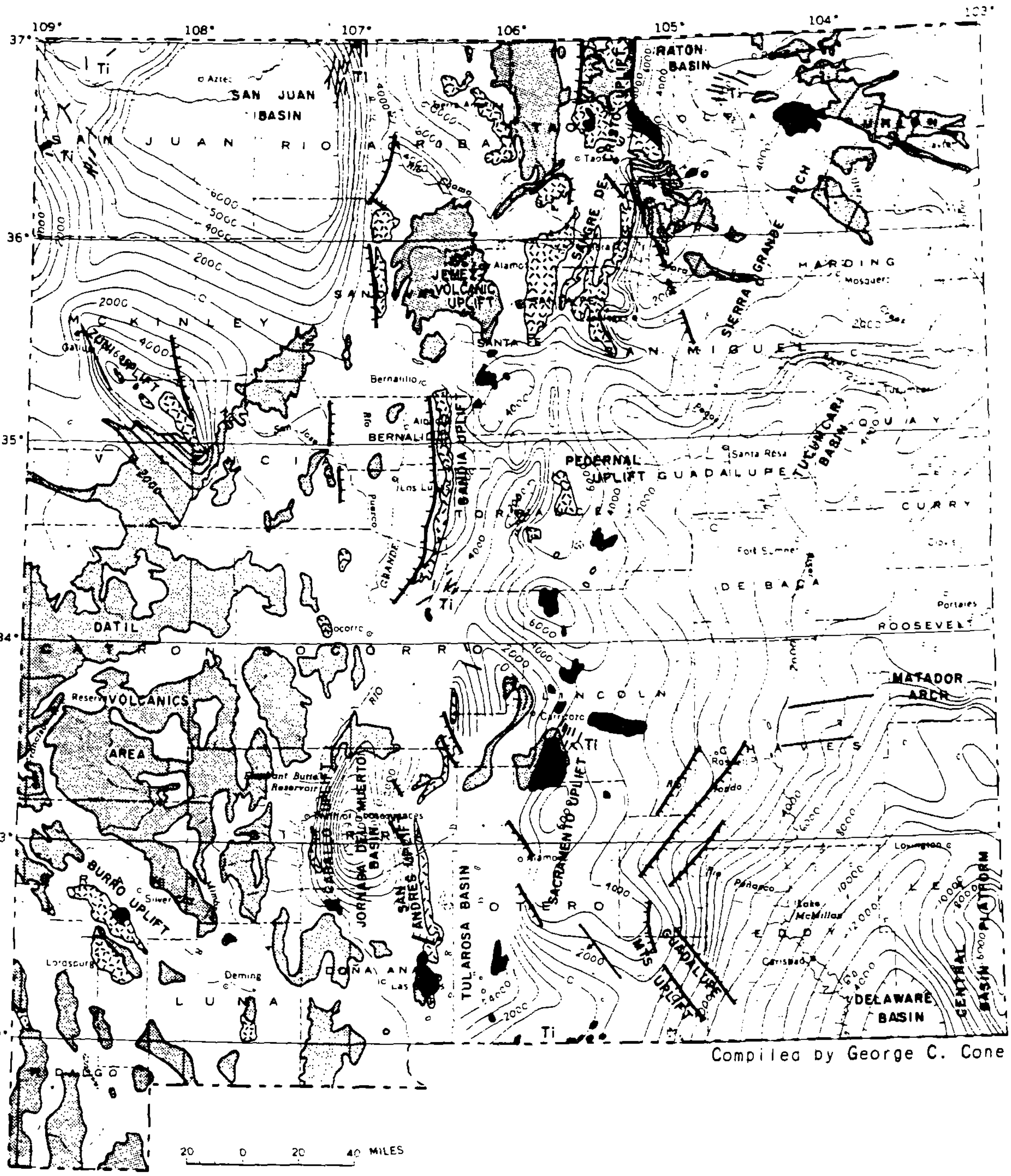
Deformation of the earth's crust is a long and continuing evolutionary process that results in the development of land forms and changing geologic environments. Mountains and basins present today in New Mexico reflect a relatively late episode in the structural history of the region (fig. 7). Some modern geologic structures may, however, be related to structural weakness in the earth's crust that first developed in Paleozoic, or Precambrian time, but continuing folding, faulting, and crumpling of rocks has masked much of the earlier structural history.

The relatively small exposures of Precambrian rocks limit the regional interpretation of the origin and history of these rocks. Seaways were present and sediments were deposited. Later these sediments were lithified, subjected to regional stresses, and intruded by igneous rocks. The lithified and metamorphosed sediments are preserved in the form of schist, quartzite, and gneiss. In the Sandia and Manzano uplifts, east and southeast of Albuquerque, and in parts of southeastern New Mexico there was some volcanic activity during Precambrian time.

During much of Paleozoic time the relief in New Mexico was low and intermittent encroachment of seas over the area was characteristic. Structural movements were probably confined to low regional warping of the earth's crust. During late Paleozoic (Pennsylvanian and Early Permian) time there was local mountain building and land masses were lifted above the surrounding sea. This uplift, and accompanying erosion of rocks, may account in part for the absence of lower Paleozoic rocks over much of north-central New Mexico. At this time the Sierra Grande arch, Pedernal arch, Matador arch, Central Basin platform, and the Zuni uplift were formed. These uplifts, sometimes called the Ancestral Rocky Mountains, contributed sediments to adjoining basins during Pennsylvanian and earliest Permian time. A remnant of the Pedernal arch forms the present Pedernal Hills in Torrance County. The Zuni uplift was rejuvenated during Tertiary time and is a prominent landmark in western New Mexico today. Other uplifts that were in existence in Early Permian time are now covered by strata deposited in Permian and later time. The cores of those uplifts have been found during drilling for petroleum.

During Mesozoic time tectonism was relatively mild in the New Mexico region. In Jurassic time the eastward trending Navajo highland—an area of low relief and nondeposition—existed in central New Mexico. Owing to the presence of this highland, strata of Jurassic age are not found, and may never have been deposited, in the southern half of the State. During Cretaceous time gentle crustal warping resulted in encroachment of seaways and the oscillation of shorelines in the northwestern part of New Mexico, and possibly elsewhere. At this time highlands were present in western Arizona and, during Late Cretaceous time, in southwestern New Mexico. Volcanoes may have been active in southwestern New Mexico.

Regional uplift accompanied by folding and local thrust faulting was the dominant tectonic activity in latest Cretaceous and earliest Tertiary time. Regional tectonic forces were probably compressional as contrasted with tensional stress of later Tertiary time. At least



EXPLANATION

Thrust fault
Sawteeth on upper plate

Normal fault
Hachures on downthrown side

Monoclinal flexure

Ti
Intrusive bodies of probable Tertiary age

Volcanic rocks of Quaternary and Tertiary age

Rocks of Precambrian age

4000
Structure contours on Precambrian surface
Contour interval 1,000 feet. Datum is sea level. Modified from Foster and Stipp, 1961

FIGURE 7.—Generalized tectonic map of New Mexico.

as early as Oligocene time tensional stress resulted in normal faults and widespread volcanic activity. The Datil volcanic field, Mount Taylor, and local igneous intrusions were developed at this time. During late Tertiary time most of the mountains and basins that are part of the present landscape of New Mexico were formed.

Late Tertiary igneous activity has produced relatively high and well-known landmarks. Intrusion of igneous rock from magmas into the earth's crust formed the Organ Mountains near Las Cruces, parts of Sierra Blanca in southern Lincoln County, and the Ortiz Mountains in Santa Fe County. Explosive volcanism formed parts of the Jemez volcanic plateau and less violent volcanic activity resulted in the building of Mount Taylor in McKinley and Valencia Counties.

An understanding of the sequence of structural events is significant to the location of mineral resources. Magmatic differentiation of igneous rocks during igneous intrusion results in the formation of pegmatites and other concentrations of minerals. Contact metamorphic deposits are formed along the margins of igneous intrusions. The movement of mineral-bearing solutions and gases in faults and fissures results in the concentration of minerals. Tilting of strata results in the movement of mineralizing fluids, water, and petroleum, in the rocks. The relative position of shorelines to sea and land are at times the key to the location of coal and petroleum resources.

Economic Geology

The economic value of a mineral resource is determined by the cost of production, cost of transportation to market, and by the demand for the commodity. Costs and demand vary with fluctuations in local or national economy, advances in the technological fields of exploration and exploitation, and increases in requirements by industry and the expanding population. A resource that cannot be developed profitably today may become the basis for a profitable enterprise in the future because of these constantly changing sociologic, technologic, and economic factors.

Once a mineral resource is exhausted it cannot be replaced. This fact of depletion is a distinctive characteristic of mineral economics and creates problems both in concepts of conservation and execution of resource development. For this reason, efficient development, intelligent use, and continuing search for new or substitute mineral resources are of importance to economic growth. Advances in the techniques of exploration and processing of mineral resources have been successful in meeting the most fundamental needs of the nation's economy to date. However, with depletion of high-grade deposits it will become necessary to locate and develop deposits that are of lower grade, particularly those that give promise of yielding more than one mineral commodity, others that are deeply buried, and still others that are farther from markets.

The accumulation of a mineral or rock to form an economic deposit is the result of one or more specific geologic processes, and therefore each type of mineral resource is limited in distribution to certain geologic environments. In fact, environments conducive to the formation of mineral deposits are so restricted in nature that it has been estimated that during the past 50 years, 90 percent of the Nation's gold, silver, copper, lead, and zinc has come from a total area of less than 1,000 square miles (Fowler and others, 1955, p. 7).

The geologic occurrence of all mineral deposits follows natural laws that allow basic predictions. Mineral fuels, such as petroleum, natural gas, and coal, are natural products of organic decay and recomposition in a sedimentary environment, and these resources are found in sedimentary rocks. In New Mexico these rocks are best preserved in the thick sedimentary deposits in the San Juan and Delaware basins. Petroleum and natural gas are found in these basins in rocks of Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, Permian, and Cretaceous ages.

Extensive deposits of coal occur in New Mexico in rocks of Cretaceous age in the San Juan Basin, and of Cretaceous and Paleocene ages in the Raton Basin. Rocks of Cretaceous age also contain coal deposits in the Carthage, Sierra Blanca, Hagen (Una del Gato), and Tijeras basins.

Other minerals are concentrated in deposits by solutions or gases emanating from deep-seated bodies of magma. These deposits are usually found in association with igneous and metamorphic rocks and occur within, or adjacent to, mountain uplifts. Some occur as veins along fractures, some as bodies that have replaced favorable rocks, and some as disseminated mineral grains in large masses of igneous rock.

Veins occur in New Mexico in the Lordsburg, Silver City, Mogollon, Lake Valley, and Magdalena districts. They have produced gold, silver, copper, and nonmetallic minerals. Replacement bodies of ore occur in wall rocks near veins or in the vicinity of igneous intrusions. Such deposits have produced lead in the Kingston, Hillsboro, Lake Valley, and other districts in New Mexico. Disseminated copper deposits are mined in the Silver City region.

Some minerals of economic importance are concentrated by processes of weathering and erosion of uplifted areas, and occur as products of deposition. These deposits include vast accumulations of sand and gravel in New Mexico, placer gold, and some clay deposits. Other deposits are enriched by weathering and oxidation.

Some rocks are of direct economic value. These include potash, salt, gypsum, perlite, pumice, granite, and travertine. Some of these have multiple uses in the construction industry either as aggregate or as building stone. Some sandstone is useful as building stone or, where composed of relatively pure silica, in the manufacture of glass. Limestone may likewise be quarried and used as building stone or processed and used in the manufacture of cement.

Many maps in this report show a trend of mineral occurrences in a broad belt across the State from the north-central part southwestward to the southwest corner. The presence of this belt of mineral occurrences has long been recognized (Lindgren and others, 1910). The interpretation of the belt is, at present, conjectural. It may be related to deep-seated geologic processes or it may be the fortuitous exposure of mineral deposits by erosion. However, trends of this type are a subject of serious study by geologists and the gathering of data, plotting of related data on maps, and the regional interpretation of such maps may lead to finding of other mineral occurrences.

TOPOGRAPHIC AND GEOLOGIC MAPPING

A map showing the topography of New Mexico has been published by the U.S. Geological Survey at a scale of 1:500,000. Topographic maps showing drainage, culture, and contours drawn on lines of equal elevation have been published for many individual areas in the State (fig. 8).

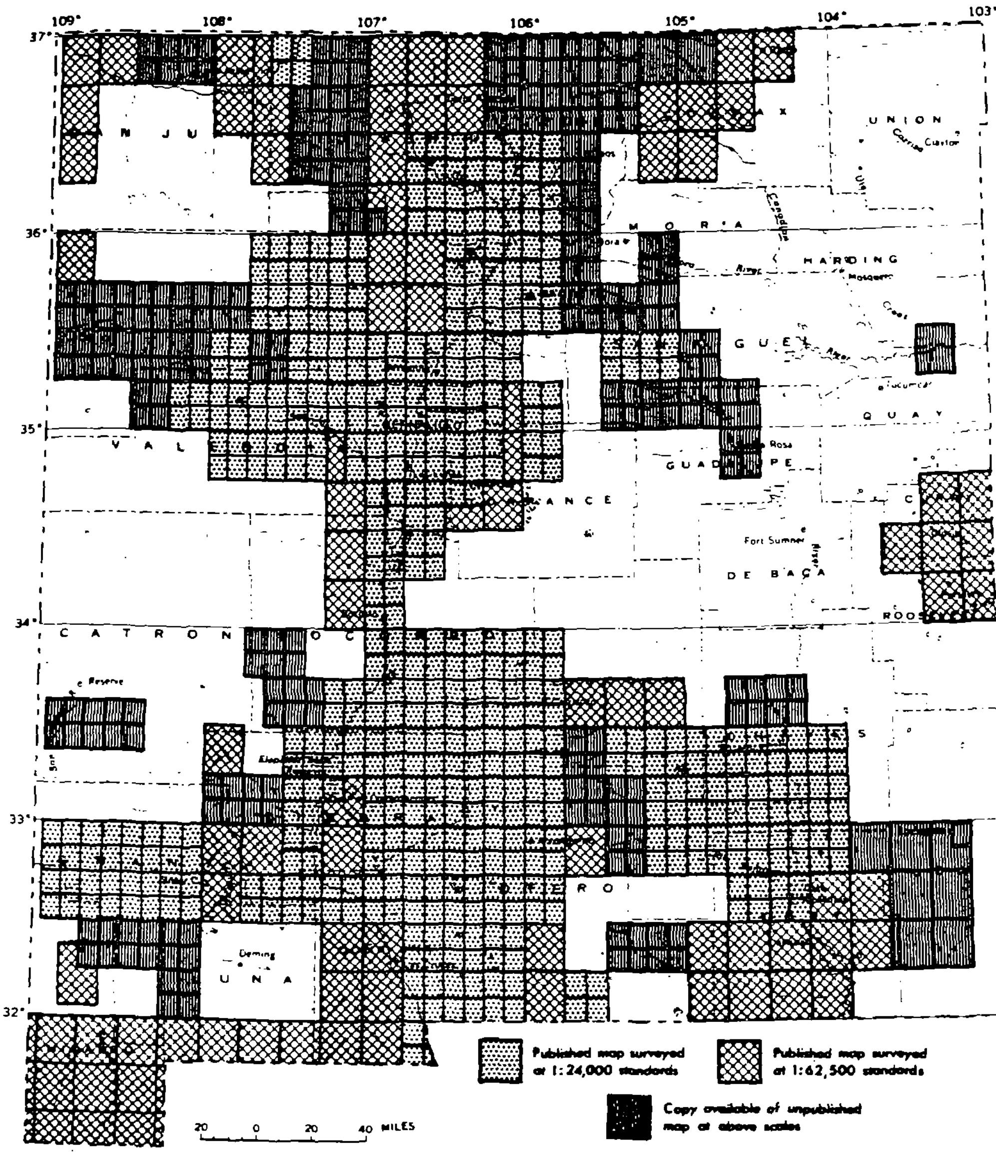
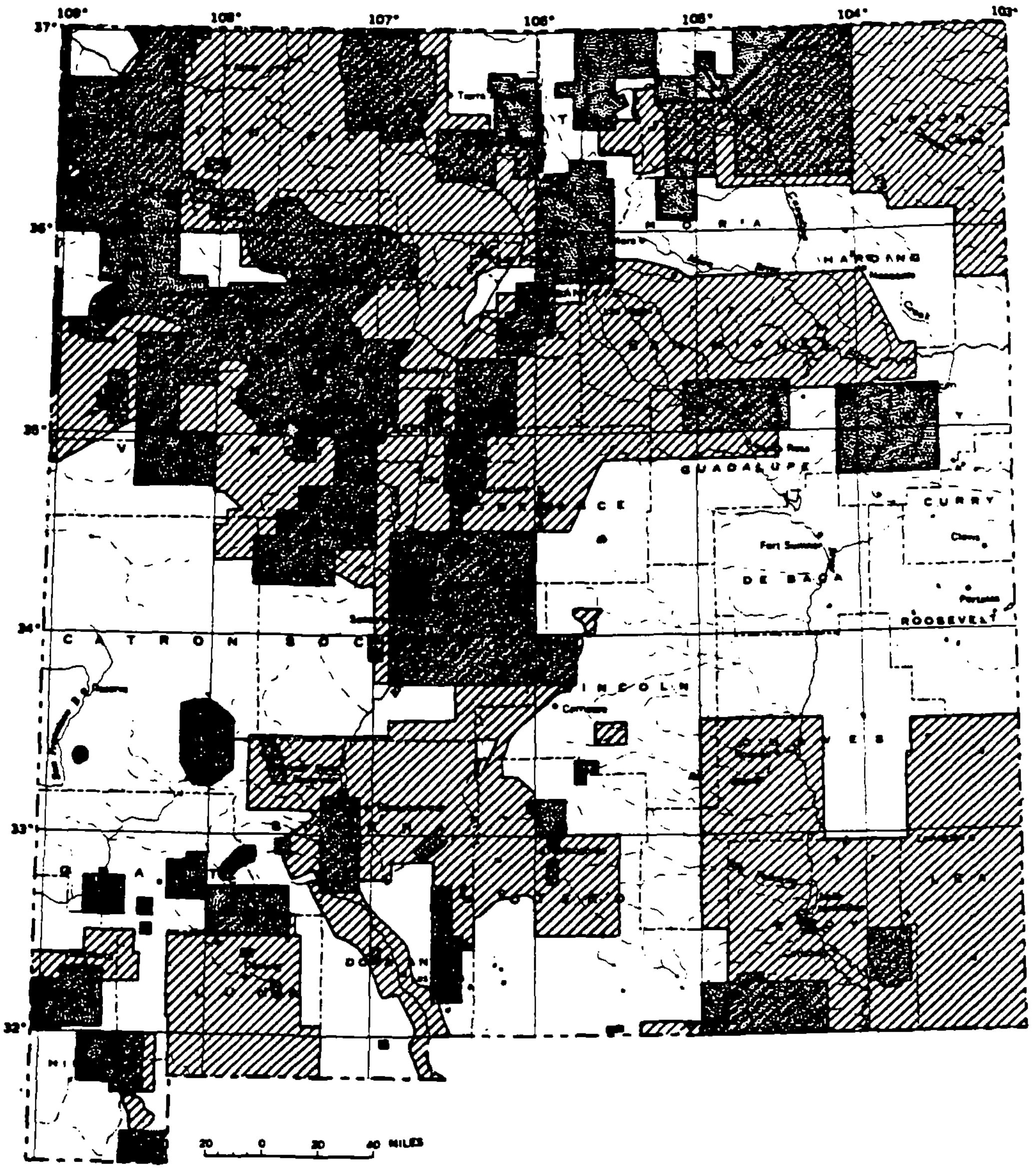


FIGURE 8.—Published and unpublished topographic maps in New Mexico, September 1964

Geologic maps show rock units exposed at the surface. Geologic maps have been published that cover a little more than one half the State (fig. 9). These maps are published either individually or as parts of geologic reports. They have been published mainly by the U.S. Geological Survey, the New Mexico Bureau of Mines and Mineral Resources, and the University of New Mexico. A geologic map of the



EXPLANATION

Areas covered by published geologic maps at scales 1:63,360 and larger. Photogeologic and incomplete maps are not included

Areas covered by published geologic maps at scales smaller than 1:63,360 to and including 1:250,000. Incomplete maps are not included

FIGURE 9.—Published geologic maps in New Mexico, September 1964.

State at a scale of 1:500,000 has been prepared by the Geological Survey in cooperation with the New Mexico Bureau of Mines and Mineral Resources and the University of New Mexico and is now in press.

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metals, especially copper, nickel, iron, silver, and lead. As a consequence, the metal is recovered largely as a byproduct of other metal-mining and refining operations, few deposits having proved workable primarily for their cobalt content. Important cobalt-bearing minerals include a number of arsenides, sulfarsenides, sulfides, and their oxidation products. The geology and mineralogy of cobalt is treated more fully by Bastin (1939), Young (1948), Vhay *in* Davis and others (1952), and Bilbrey (1960a, 1962).

World production of cobalt in 1962 (exclusive of the Soviet Union and Red China) was 16,067 short tons. The United States consumed 5,634 short tons in 1962, a new record 5 percent higher than the previous record in 1952 (Bilbrey and Clarke, 1963; U.S. Bureau of Mines, "Commodity Data Summaries," 1964). Domestic production in 1962 was not reported inasmuch as it came from a single producer in Pennsylvania. Mine production in the United States from 1940 to the present has ranged from 67 to 2,422 short tons, largely from magnetic iron ores in Pennsylvania, lead ores in Missouri, and copper-cobalt ores in Idaho (Bilbrey, 1962). Major imports in recent years have come from the Republic of the Congo, Belgium-Luxembourg, and West Germany.

The principal known deposits of cobalt in New Mexico are those of the Black Hawk district in Grant County, which were worked only for their silver content (summarized under nickel). Smaltite (Cobalt-nickel arsenide) was identified by R. A. Zeller, Jr., among the metallic minerals in the Creeper mine, Sylvanite district, Hidalgo County (Northrop, 1959). Very small amounts of cobalt have been detected spectrographically in manganese-oxide ores in a number of localities, the amounts ranging up to 0.15 percent in the Red Hill deposit, Luis Lopez district, Socorro County (Hewett and others, 1963). Cryptomelane and hollandite from the Black Feather claims in the same district yielded 0.59 percent cobalt oxide (CoO) by chemical analysis (Hewett and Fleischer, 1960).

URANIUM

(By L. S. Hilpert, Salt Lake City, Utah)

Review of Industry

Uranium consists of a mixture of the isotopes U^{238}, U^{235}, and U^{234}. The isotope U^{238} constitutes more than 99 percent of natural uranium and can be converted to fissionable plutonium. The naturally fissionable U^{235} isotope and plutonium are the principal ingredients in fuel for nuclear reactors and in weapons; these are the major uses for uranium. Minor amounts of uranium are also used in the chemical, ceramic, and electrical industries.

Consumption of uranium was small prior to World War II, but with the development of the nuclear bomb it became a metal of great strategic importance. During the late 1940's and early 1950's, because of the domestic shortage, the United States obtained its supply mostly from foreign sources, first largely from the Belgian Congo and then from Canada. By the mid-1950's the domestic supply could largely satisfy domestic needs, and foreign purchases were gradually decreased. By 1963 domestic producers supplied 62 percent of total purchases, the remainder being supplied mostly by Canada and the Republic of South Africa (Baroch, 1964).

Uranium has been a commodity of great importance to New Mexico since the early 1950's. Although uranium minerals have been known in New Mexico for many years (Jones, 1904, pp. 113, 186, 342, 344) they were little more than curiosities until carnotite deposits were discovered in 1918 west of Shiprock, San Juan County, and uraniferous minerals were discovered about 1920 in the White Signal and Black Hawk districts, Grant County (Hess, 1922, p. 416). A small amount of ore was mined from these deposits for pharmaceutical purposes (Lovering, 1956, p. 329). In the period from 1942 to 1944 a few thousand tons of ore were mined from the Shiprock area for the vanadium content. Subsequently, during World War II, some of the mill tailings of this ore were re-treated for uranium recovery.

In 1948 prospecting was stimulated by the U.S. Atomic Energy Commission with the ore-buying schedule announced in Circular 5.[1] New deposits were found shortly thereafter in many parts of the State, notably in limestone at the outcrop near Grants, McKinley County, in 1950; in sandstone at the outcrop near Laguna, Valencia County, in 1951 (the Jackpile deposit); and in large subsurface deposits in sandstone near Ambrosia Lake, McKinley County, in 1955. Development of these deposits and others was rapid; the output in 1956 exceeded 1 million tons of ore and it climbed until it reached a peak in 1960 of about 3.8 million tons of ore (table 27).

TABLE 27.—*Uranium ore production in New Mexico*

Years	Short tons [1]	Grade (percent U_3O_8)	Value [1] [2]
1918–41	Negligible		
1942–44	[3]		[4] Negligible
1945–49	Negligible		
1950	[5] 6,000	[5] 0.21	$100,000
1951	[5] 2,000	[5] .24	[5] 61,000
1952	[5] 23,000	[5] .22	[6] 546,500
1953	[5] 85,000	[5] .25	[6] 2,067,000
1954	[5] 196,000	[5] .36	[6] 6,303,000
1955	[5] 262,000	[5] .25	[7] 5,270,000
1956	1,105,183	.26	24,086,234
1957	1,175,742	.22	20,538,086
1958	1,888,499	.26	32,264,000
1959	3,269,826	.21	53,463,000
1960	3,793,494	.21	61,827,000
1961	3,631,036	.22	62,482,000
1962	3,478,238	.23	63,504,000
1963	[8] 2,304,577	.22	[8] 41,372,000
Total (rounded) and average	21,225,000	.23	374,000,000

[1] Data from U.S. Bureau of Mines Minerals Yearbook, except as noted.
[2] F.o.b. mine value, including base price, grade premiums, and development allowance; vanadium excluded.
[3] Few thousand.
[4] Mined for vanadium; small amount later reprocessed for uranium recovery.
[5] Compiled from file data, available by courtesy of U.S. Atomic Energy Commission.
[6] Calculated on base price, grade premiums, and development allowance for yearly average grade plus following production bonuses: 1951, $21,401; 1952, $134,789; 1953, $303,163; and 1954, $187,685 (J. A. Patterson, oral communication, September 1964).
[7] Prorated estimate based on July–December 1955 tonnage, grade, and ore value figures, from Minerals Yearbook.
[8] U.S. Bureau of Mines Mineral Industry Surveys, June 1964.

[1] See Atomic Energy Commission Regulations, pt. 60, Domestic Uranium Program Circulars 1 to 6, inclusive, Apr. 9, 1948, June 15, 1948, Feb. 7, 1949, and June 27, 1951.

The output from New Mexico has been of vital importance to the Nation as well as to the State. In the 1957–63 period uranium production in New Mexico was 40 percent of the total for the country. The dollar values of the uranium ores mined have ranged from about 4 and 3 percent of the State's total mineral output, in 1956 and 1957, respectively, up to more than 9 percent in 1960 and 1962. Although there has been a general decline in output since 1960, New Mexico will probably continue to hold the same general proportion of total U.S. output for at least the next few years. The recent decline has resulted primarily from the saturated uranium market. Fringe benefits have been permitted to lapse, restrictions have been imposed on mine allotments, and the price paid for mill concentrates has been reduced. The bonus paid for initial production of uranium ores from new mines terminated February 28, 1957, and payments made for contained V_2O_5 were discontinued on ores that were too low in vanadium for efficient vanadium recovery. In 1962, a stretchout program for domestic uranium procurement for the period from January 1, 1967, to December 31, 1970, was announced. It provides for deferring delivery to 1967 and 1968 of some uranium concentrates which were originally contracted for delivery before 1967, and for purchase of an additional amount of concentrates in 1969 and 1970 equal to the amount deferred to 1967 and 1968. In 1969 and 1970 the maximum price is to be \$6.70 per pound of contained U_3O_8. This general cutback resulted in the closing in 1963 of one uranium mill in New Mexico, leaving four operating mills and one on standby status in 1964. The combined rated capacity of these mills is about 10,000 to 11,000 tons of ore per day.[1]

Peneconcordant Deposits

Uranium deposits in New Mexico occur in rocks of many ages and lithologic types. Two general types of deposits, peneconcordant and vein, occur in New Mexico. The most abundant, largest, and most productive are the peneconcordant deposits (Finch, 1959a). These occur in sedimentary rocks and are nearly concordant (parallel) to the bedding. The deposits are found most often in thick fluvial sandstone and conglomeratic sandstone which has been bleached gray or stained brown. Such deposits have been referred to as sandstone-type deposits. To a lesser extent, peneconcordant deposits occur in lignite and carbonaceous shale, and in limestone. The deposits are roughly tabular to lenslike, tending to be elongate and parallel, or nearly so, to such sedimentary features as sandstone lenses and bedding structures. Most of the deposits are restricted to certain favorable stratigraphic units, where they occur in clusters, and these clusters in turn tend to occur in belts. The recognition of these features is useful in exploration for hidden deposits and in making resource appraisals. Size of the deposits ranges from local masses that contain less than a ton of material to large masses that contain as much as several million tons. The grade ranges from trace amounts to several percent uranium but the average grade of the ore is about 0.25 percent U_3O_8.

The mineralogy is complex and varies between deposits, depending on the relative contents of uranium and vanadium and copper and

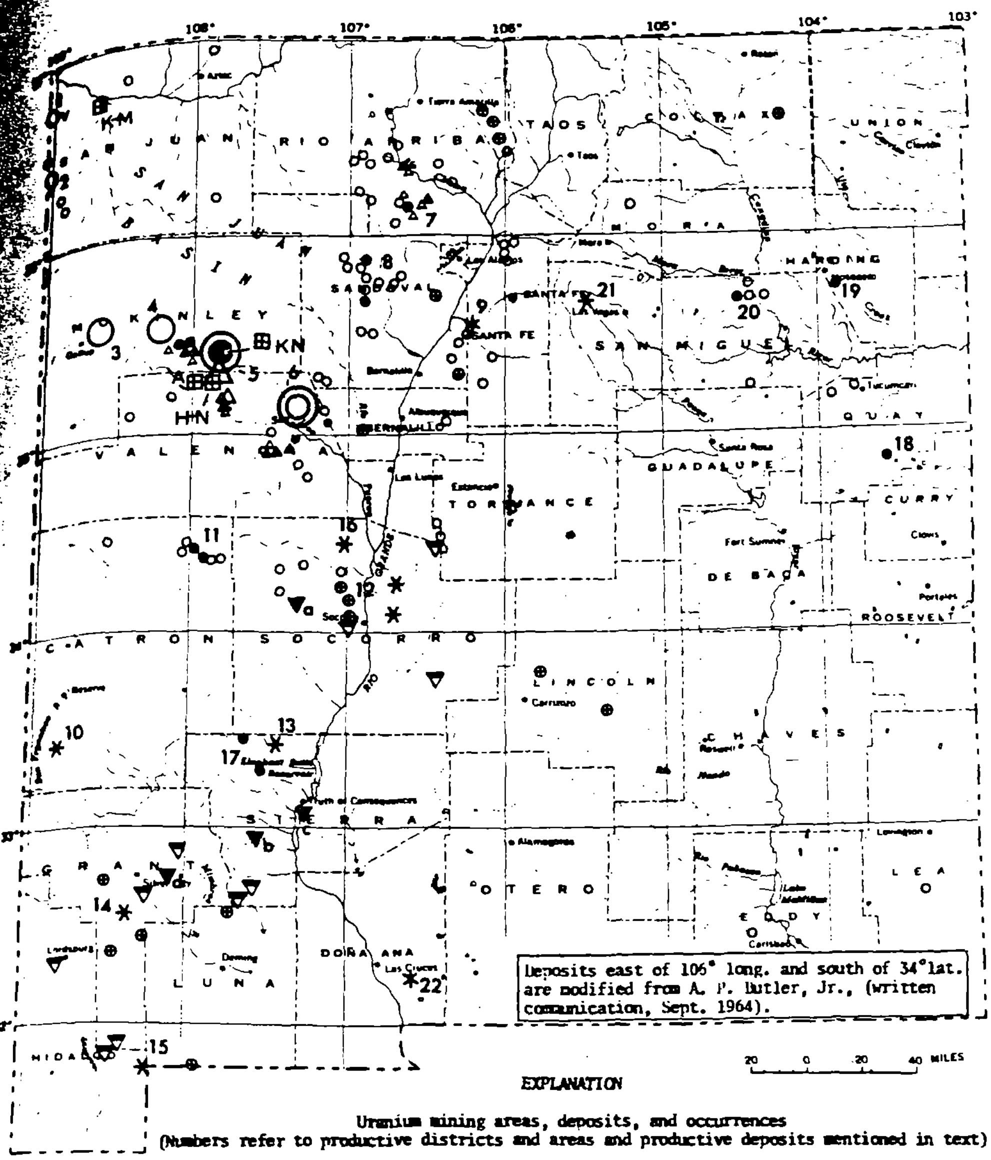
[1] U.S. Atomic Energy Commission Press Release 356, Washington, D.C., and Grand Junction, Colo., Nov. 17, 1962.

the degree of oxidation. The vanadiferous deposits generally range in uranium to vanadium ratio from about 1:1 to 1:10 and contain traces of copper and other metals, but in general the copper content is less than in the nonvanadiferous deposits. The so-called nonvanadiferous deposits actually contain small amounts of vanadium and also minor amounts of copper and other metals, but locally contain as much as several percent copper. Those that have yielded copper ore have been referred to as red beds copper deposits.

Near the surface, the vanadiferous deposits consist largely of the uranyl vanadates, carnotite and tyuyamunite, and various other vanadium minerals; and the nonvanadiferous deposits contain the uranium hydrous oxide, becquerelite. Where much copper is present the minerals are commonly the hydrous phosphate (torbernite) and hydrous sulfate (johannite) of copper and uranium and hydrous carbonates of copper.

Below the surface and generally below the water table, the unoxidized analogs of these minerals are principally uraninite (pitchblende), coffinite, montroseite, and micaceous vanadium silicates in the vanadiferous deposits; uraninite or coffinite in the nonvanadiferous deposits; and uraninite and variable amounts of iron and copper sulfides where much copper is present. The mineralogy is discussed more completely by Hess (1933), Botinelly and Weeks (1957), Finch (1959b), Garrels and Larson (1959), Laverty and Gross (1956), Truesdell and Weeks (1959), and Granger (1963).

Peneconcordant deposits in New Mexico occur in sedimentary rocks ranging in age from Paleozoic to Tertiary and occurring in many stratigraphic units. The important ones, however, are largely confined to rocks of Jurassic age in the northwestern part of the State. These and the less important ones are reviewed in ascending stratigraphic order. The productive districts, areas, and deposits are identified by number on figure 47 and most of the individual mines are listed in tables 28 to 30; others are named in the text. Unproductive deposits or occurrences are shown by symbol only and, when not cited in the text, can generally be identified and located in Hilpert and Corey (1955, pp. 104–118), Butler, Finch, and Twenhofel (1962), and Anderson (1955).



EXPLANATION

Uranium mining areas, deposits, and occurrences
(Numbers refer to productive districts and areas and productive deposits mentioned in text)

Type of deposits	Host rock	Tons of ore shipped through 1963: >10,000,000	1,000,000-10,000,000	100,000-1,000,000	10,000-100,000	1-10,000	Occurrence 1/
Deposits penecon-cordant with sedi-mentary features of the enclosing rocks	Sandstone, silt-stone, and carbonaceous shale 2/	◉	◎	○	○ 3/	•	∘
	Limestone 2/			△	△	▲	△
Veins, breccia zones, stockworks, and related types	(See text)					✱	•

1/ Material containing at least 0.01 percent U_3O_8 or recognizable uranium minerals and 0.01 or more eU_3O_8.
2/ In McKinley and Valencia Counties, individual productive deposits are not numbered or described and are not shown within areas of large symbols.
3/ A "v" by symbol (Ov) indicates deposits are vanadiferous.

Vanadate deposits
▼ Reported production
▽ No reported production
(Letters refer to districts mentioned in text)

⊞ Uranium mill operating in 1964
(A, The Anaconda Co.; K-M, Kerr-McGee Oil Industries; KN, Kermac Nuclear Fuels Corp.; H-N, Homestake-Sapin New Mexico Partners)

FIGURE 47.—Uranium and vanadium in New Mexico.

TABLE 28.—*List of mines in the Todilto limestone*

Name	*Location (section, township, and range, New Mexico Principal Meridian)*
McKinley County:	
Ambrosia Lake district (locality 5, fig. 47):	
Barbara J. No. 1.	NE¼ sec. 30, T. 13 N., R. 9 W.
Barbara J. No. 3.	NE¼ sec. 30, T. 13 N., R. 9 W.
Dalco No. 1	NW¼ sec. 30, T. 13 N., R. 9 W.
Faith	NW¼ sec. 29, T. 13 N., R. 9 W.
Flat Top No. 3.	SE¼ sec. 30, T. 13 N., R. 9 W.
Flat Top No. 4.	SE¼ sec. 30, T. 13 N., R. 9 W.
Hanosh	NE¼ sec. 26, T. 13 N., R. 10 W.
Haystack	NW¼ sec. 19, T. 13 N., R. 10 W.
Haystack No. 2.	Center SW¼ sec. 13, T. 13 N., R. 11 W.
Manol	SW¼ sec. 30, T. 13 N., R. 9 W.
Red Point lode.	NW¼ sec. 16, T. 13 N., R. 10 W.
Rimrock	SW¼ sec. 30, T. 13 N., R. 9 W.
Section 18, SW¼	SW¼ sec. 18, T. 13 N., R. 10 W.
Section 18, SE¼	SE¼ sec. 18, T. 13 N., R. 10 W.
Section 19, NE¼	NE¼ sec. 19, T. 13 N., R. 10 W.
Section 23	S½SE¼ sec. 23, T. 13 N., R. 10 W.
Section 24	NE¼ sec. 24, T. 13 N., R. 11 W.
Section 25	Sec. 25, T. 13 N., R. 10 W.
Section 31	N½ sec. 31, T. 13 N., R. 9 W.
Section 33	Sec. 33, T. 14 N., R. 9 W.
Smith Lake district, (locality 4, fig. 47):	
Billy the Kid	NE¼ sec. 19, T. 14 N., R. 11 W.
Glover	NW¼ sec. 20, T. 14 N., R. 11 W.
Lawrence Elkins.	NE¼ sec. 24, T. 14 N., R. 12 W.
Section 19 (Greer, Warren, & McCormack).	NE¼ sec. 19, T. 14 N., R. 11 W.
Section 19 (Maddox & Teague).	Sec. 19, T. 14 N., R. 11 W.
Section 21	SW¼ sec. 21, T. 14 N., R. 11 W.
T. No. 2	SW¼ sec. 28, T. 14 N., R. 11 W.
T. No. 10	SW¼ sec. 28, T. 14 N., R. 11 W.
Tom Elkins	SE¼ sec. 24, T. 14 N., R. 12 W.

TABLE 28.—*List of mines in the Todilto limestone*—Continued

Name	*Location (section, township, and range, New Mexico Principal Meridian)*
Rio Arriba County:	
Locality 7 (fig. 47):	
Wasson	NE¼ sec. 28, T. 23 N., R. 4 E.
Valencia County:	
Ambrosia Lake District (locality 5, fig. 47):	
Black Hawk	SE¼ sec. 4, T. 12 N., R. 9 W.
Bunney	SE¼ sec. 4, T. 12 N., R. 9 W.
Cedar No. 1	SE¼ sec. 20, T. 11 N., R. 9 W.
Christmas Day	NE¼ sec. 4, T. 12 N., R. 9 W.
Double Jerry	NW¼ sec. 3, T. 12 N., R. 9 W.
F-33	SE¼ sec. 33 and SW¼ sec. 34, T. 12 N., R. 9 W.
Gay Eagle	SE¼ sec. 4, T. 12 N., R. 9 W.
La Jara	SE¼ sec. 15, T. 12 N., R. 9 W.
Last Chance	NE¼ sec. 8, T. 12 N., R. 9 W.
Lone Pine No. 3.	NE¼ sec. 8, T. 11 N., R. 9 W.
Red Bluff No. 3.	NE¼ sec. 4, T. 12 N., R. 9 W.
Red Bluff No. 5	NE¼ and NW¼ sec. 4, T. 12 N., R. 9 W.
Red Bluff No. 7.	SW¼ sec. 4, T. 12 N., R. 9 W.
Red Bluff No. 8	SE ¼ sec. 4, T. 12 N., R. 9 W.
Red Bluff No. 9.	NE¼ sec. 4, T. 12 N., R. 9 W.
Red Bluff No. 10.	SE ¼ sec. 4, T. 12 N., R. 9 W.
Section 9	NW¼ sec. 9, T. 12 N., R. 9 W.
Tom 13	SE¼ sec. 4, T. 11 N., R. 9 W.
UDC No. 5	SE¼ sec. 4, T. 12 N., R. 9 W.
Zia [1]	SW¼ sec. 15, T. 12 N., R. 9 W.
Laguna district (locality 6, fig. 47):	
Crackpot	NW¼ sec. 8, T. 8 N., R. 5 W.
Paisano	NW¼ sec. 16, T. 8 N., R. 6 W.
Sandy [1]	SE¼ sec. 22, T. 9 N., R. 5 W.

[1] Partly in Entrada Sandstone.

Name	Location (section, township, and range, New Mexico Principal Meridian)
Harding County:	
Locality 19 (fig. 47):	
Polita No. 2	Sec. 5, T. 17 N., R. 29 E.
McKinley County:	
Ambrosia Lake district (locality 5, fig. 47):	
Ann Lee	Sec. 28, T. 14 N., R. 9 W.
Beacon Hill	SE¼ sec. 18, T. 13 N., R. 9 W.
Blue Peak	NE¼ sec. 24, T. 13 N., R. 10 W.
Bob Cat	NE¼ (?) sec. 24, T. 13, N., R. 10 W.
Bucky	SE¼ sec. 14, T. 14 N., R. 10 W.
Cliffside	SW¼ sec. 36, T. 14 N., R. 9 W.
Dog Incline No. 1.	NE¼ sec. 20, T. 13 N., R. 9 W.
Dysart No. 1	S½ sec. 11, T. 14 N., R. 10 W.
Hogan	S½ sec. 14, T. 13 N., R. 9 W.
Malpais	Center S½N½ sec. 20, T. 13 N., R. 9 W.
Marquez	Center sec. 23, T. 13 N., R. 9 W.
Mesa Top No. 7 (Moe).	Center W½ sec. 20, T. 13 N., R. 9 W.
Mesa Top No. 18 and 20.	SW¼ sec. 20, T. 13 N., R. 9 W.
Pat	NE¼ sec. 4, T. 13 N., R. 10 W.
Poison Canyon.	NE¼ and SE¼ sec. 19, T. 13 N., R. 9 W.
Sandstone	Sec. 34, T. 14 N., R. 9 W.
Centennial (Section 8).	NW¼ sec. 8, T. 13, N., R. 9 W.
Section 10	E½ sec. 10, T. 14 N., R. 10 W.
Section 15	SE¼ sec. 15, T. 14 N., R. 10 W.
Section 17	S½ sec. 17, T. 14 N., R. 9 W.
Section 21	NE¼SW¼ sec. 21, T. 13 N., R. 9 W.
Section 22	E½ sec. 22, T. 14 N., R. 10 W.
Sectiou 23	Sec. 23, T. 14 N., R. 10 W.
Section 24	Sec. 24, T. 14 N., R. 10 W.
Section 25	Sec. 25, T. 14 N., R. 10 W.
Section 30 (Kermac)	Sec. 30, T. 14 N., R. 9 W.
Section 32	N½ sec. 32, T. 14 N., R. 9 W.
Section 33	Sec. 33, T. 14 N., R. 9 W.
Section 36	NE¼ sec. 36, T. 14 N., R. 10 W.
Taffy (Bonanza.	Secs. 11, 14, 15, T. 12 N., R. 9 W.
Gallup district (locality 3, fig. 47):	
Church Rock	NE¼ sec. 17, T. 16 N., R. 17 W.
CD & S	SE ¼ sec. 35, T. 16 N., R. 17 W.
Foutz No. 1	NW¼ sec. 4, T. 15 N., R. 16 W.
Foutz No. 2	NE¼ sec. 5, T. 15 N., R. 16 W.
Foutz No. 3 YJ.	SE¼ sec. 31, T. 16 N., R. 16 W.
Westwater No. 1.	S½ sec. 12, T. 15 N., R. 16 W.
Smith Lake district (locality 4, fig. 47):	
Alta	SW¼ sec. 5, T. 14 N., R. 11 W.
Black Jack No. 1.	Sec. 12, T. 15 N., R. 13 W.
Black Jack No. 2.	Sec. 18, T. 15 N., R. 13 W.
Evelyn	NW¼ sec. 9, T. 14 N., R. 11 W.
Francis	NW¼ sec. 8, T. 14 N., R. 11 W.
Silver Bit No. 7.	NE¼ sec. 10, T. 14 N., R. 12 W.
Silver Bit No. 15.	NE¼ sec. 10, T. 14 N., R. 12 W.
Silver Bit No. 18.	NE¼ sec. 10, T. 14 N., R. 12 W.

TABLE 29.—*List of mines in the Morrison Formation*—Continued

Name	Location (section, township, and range, New Mexico Principal Meridian)
Sandoval County:	
Locality 8 (fig. 47):	
Collins	Sec. 25, T. 17 N., R. 1 W. (projected unsurveyed land).
San Juan County:	
Chuska district (locality 2, fig. 47):	
Carl Yazzie No. 1.	NW¼ sec. 30, T. 25 N., R. 20 W.
Castle T'sosie	SE¼ sec. 11, T. 25 N., R. 21 W.
Dench Nezz	NE¼ sec. 18, T. 25 N., R. 20 W.
Dench Nezz No. 2.	NE¼ sec. 18, T. 25 N., R. 20 W.
Dench Nezz No. 3.	NW¼ sec. 18, T. 25 N., R. 20 W.
Enos Johnson	SW¼ sec. 19, T. 25 N., R. 20 W.
Enos Johnson No. 1.	NW¼ sec. 19, T. 25 N., R. 20 W.
Enos Johnson No. 2.	NW¼ sec. 19, T. 25 N., R. 20 W.
Enos Johnson No. 3.	NW¼ sec. 19, T. 25 N., R. 20 W.
H. B. Roy No. 2.	NE¼ sec. 36, T. 25 N., R. 21 W.
Horace Ben No. 1.	SE¼ sec. 19, T. 25 N., R. 20 W.
Joe Ben No. 1	NW¼ sec. 13, T. 25 N., R. 21 W.
Joe Ben No. 3	NE¼ sec. 24, T. 25 N., R. 21 W.
John Joe No. 1.	SE¼ sec. 11, T. 25 N., R. 21 W.
Kee Tohe	SE¼ sec. 11, T. 25 N., R. 21 W.
Shiprock district (locality 1, fig. 47):	
Alongo	SW¼ sec. 25, T. 29 N., R. 21 W.
BB (Lewis Barton).	Uncertain location.
BBB (Barton & Begay).	Do.
Begay No. 1	NW¼ sec. 24, T. 29 N., R. 21 W.
Canyon No. 1	NW¼ sec. 2, T. 29 N., R. 21 W., (may be in Arizona).
Canyon View	Uncertain location.
Carrizo No. 1	Do.
Cottonwood Butte.	Do.
Junction	NE¼ sec. 24, T. 29 N., R. 21 W.
King No. 2	NW¼ sec. 26, T. 30 N., R. 21 W.
King No. 6	SW corner sec. 11, T. 30 N., R. 21 W.
King Tutt	SE¼ sec. 23, T. 29 N., R. 21 W.
King Tutt No. 1.	SW¼ sec. 24, T. 29 N., R. 21 W.
King Tutt Point.	Uncertain location.
Lone Star	SW¼ sec. 35, T. 30 N., R. 21 W.
Lookout Point.	SE¼ sec. 14, T. 29 N., R. 21 W.
Nelson Point	NW¼ sec. 23, T. 29 N., R. 21 W.
Rattlesnake No. 6.	Uncertain location.
Red Wash Point.	Do.
Rocky Flats	SW¼ sec. 14, T. 30 N., R. 21 W.
Rocky Flats No. 2.	SE¼ sec. 26, T. 30 N., R. 21 W.
Rocky No. 2	Uncertain location.
Salt Canyon	NE¼ sec. 14, T. 29 N., R. 21 W.
Sam Point	Uncertain location.

TABLE 29.—*List of mines in the Morrison Formation*—Continued

Name	Location (*section, township, and range, New Mexico Principal Meridian*)
San Juan County—Continued	
Shiprock district—Continued	
Shadyside	Center N½ sec. 23, T. 29 N., R. 21 W.
Shadyside No. 2.	Center N½ sec. 23, T. 29 N., R. 21 W.
Tent	NE¼ sec. 23, T. 29 N., R. 21 W.
Valencia County	
Ambrosia Lake district (locality 5, fig. 47):	
San Mateo (section 30).	Sec. 30, T. 13 N., R. 8 W.
Laguna district (locality 6, fig. 47):	
Chaves	SE¼ sec. 22, T. 10 N., R. 3 W.
Jackpile	Parts of secs. 26 and 35, T. 11 N., R. 5 W., and center N½ sec. 2, T. 10 N., R. 5 W.
M-6	SW¼ sec. 19 and NW¼ sec. 30, T. 11 N., R. 4 W.
Paguate	Secs. 4 and 5, T. 10 N., R. 5 W., and sec. 33, T. 11 N., R. 5 W.
St. Anthony	NE¼NW¼ sec. 29, T. 11 N., R. 4 W.

NOTE.—In the Shiprock and Chuska districts, the land is unsurveyed and the mine locations are based on a projected land net.

TABLE 30.—*List of Mines in the Dakota sandstone*

Name	Location (*section, township, and range, New Mexico Principal Meridian*)
McKinley County:	
Ambrosia Lake district (locality 5, fig. 47):	
Junior	NE¼ sec. 4, T. 13 S., R. 10 W.
Sec. 5 (Westvaco).	Sec. 5, T. 13 N., R. 10 W.
Silver Spur No. 1.	Sec. 31, T. 14 N., R. 10 W.
Silver Spur No. 5.	NE¼ sec. 31, T. 14 N., R. 10 W.
Small Stake	S½SW¼ sec. 31, T. 14 N., R. 10 W.
Gallup district (locality 3, fig. 47):	
Becenti	NW¼ sec. 28, T. 15 N., R. 17 W.
Christian 16 (U).	SE¼ sec. 4, T. 15 N., R. 16 W.
Diamond No. 2.	NE¼ sec. 33, T. 15 N., R. 17 W.
Hogback	NE¼ sec. 12, T. 15 N., R. 18 W.
Santa Fe Christ (sec. 3)	SW¼ sec. 3, T. 15 N., R. 16 W.
Sandoval County:	
Locality 8 (fig. 47):	
Butler Bros. No. 1.	NE¼ sec. 23, T. 19 N., R. 1 W.

Deposits in Pennsylvanian, Permian, and Triassic rocks.—Deposits in rocks of Pennsylvanian to Triassic age are mineralogically similar, are generally nonvanadiferous, and are referred to as red beds copper deposits where worked for copper. These deposits are mostly small and occur in bleached arkosic sandstone and in carbonaceous shale lenses in close association with fossil plant debris, iron and copper sulfides, and copper carbonates. They have yielded only a few hundred tons of uranium ore, all from rocks of Permian and Triassic age. Deposits of this type also occur in steeply dipping beds of carbonaceous shale and sandstone of the Sangre de Cristo Formation, of Pennsylvanian and Permian age, in the Coyote district, Mora County (Tschanz, Laub, and Fuller, 1958), but these deposits are low in grade and have been unproductive.

Three formations of Permian age contain scattered deposits, the ...tes Formation in Eddy County, the Cutler Formation in Rio Arriba County, and the Abo Formation in Bernalillo, Sandoval, Sierra, and Torrance Counties. Some ore has been produced from the Hillfoot ...1 (NW¼ sec. 8, T. 22 N., R. 3 E.), Red Head No. 2 (SW¼ sec. 8, 22 N., R. 3 E.) and Red Bird (NE¼ sec. 8, T. 22 N., R. 3 E.) deposits in Rio Arriba County (locality 8, fig. 47), and from the Empire group (secs. 11–14, T. 10 S., R. 8 W.) and State mineral lease possibly sec. 2, T. 12 S., R. 7 W.) in Sierra County (locality 17). The Chinle Formation has yielded some ore from the Good Luck, Quay County (sec. 6, T. 7 N., R. 32 E., locality 18) (Griggs, 1955, pp. 192–194), and the Windy No. 9 (sec. 14, T. 17 N., R. 23 E., locality 19). Other scattered occurrences are found in San Miguel County in the Chinle (Baltz, 1955, pp. 36–39) or in other units of the Dockum Group; in the Salitral Shale Tongue, Agua Zarca Sandstone Member, and Poleo Sandstone Lentil of the Chinle in Rio Arriba County (Wood and Northrop, 1946); in the Dockum Group in Socorro County; and in the Shinarump(?) Member of the Chinle in Valencia County. These stratigraphic units are all of Triassic age.

Deposits in rocks of Jurassic age.—Rocks of Jurassic age contain the most important uranium deposits in New Mexico. Through 1963, they have yielded about 21 million tons or 99 percent of the ore, of which the Morrison Formation has yielded about 20 million tons (95 percent) and the Todilto Formation nearly 1 million tons (4 percent). The most important deposits are largely restricted to the southern margin of the San Juan Basin in the Ambrosia Lake (locality 5), Laguna (locality 6), Smith Lake (locality 4), and Gallup (locality 3) districts and, of less importance, the Shiprock (locality 1) and Chuska (locality 2) districts.

The lowermost deposits are in the Todilto Formation, which consists of a lower limestone unit 5 to 35 feet thick and an upper gypsum-anhydrite unit 0 to 75 feet thick. The deposits, generally nonvanadiferous, are in the limestone unit where it has been deformed by interformational folding and faulting. Some deposits are irregular in shape but most are elongate and range from 20 to 30 feet in width and from 100 to several thousand feet in length. Although most of the ore is in the lower part of the limestone, it may occur throughout the unit, and thus the ore bodies vary in thickness from a few feet to 20 feet or more. In a few places they extend into the top few feet of the underlying Entrada Sandstone or a few feet into the overlying Summerville Formation. Most of the deposits that have been mined are in the Ambrosia Lake and Laguna districts (localities 5 and 6) where ore has been shipped from more than 40 properties (table 28). A few thousand tons have been mined from the Smith Lake district (locality 4; table 28) and a small amount has been produced from the Wasson deposit in Rio Arriba County (locality 7). Details on these deposits and their stratigraphic relations are given by Gabelman (1956a, pp. 387–400), Hilpert and Moench (1960, pp. 429–464), and McLaughlin (1963, p. 149).

The uranium-bearing Morrison Formation is distributed over the northern one-third of New Mexico and extends into adjoining States. It consists mostly of claystone or mudstone interbedded with thick lenses of sandstone, some of which are conglomeratic. In northwestern New Mexico the formation is divided into four members. The lowest member, the Salt Wash, crops out only in the extreme northwestern corner of the State, where it contains vanadiferous uranium deposits. The other three members, the Recapture, Westwater Canyon, and Brushy Basin, named in ascending order, extend over most of northwestern New Mexico; the upper two members contain the largest known uranium deposits in the State, those located between Gallup and Albuquerque. The Morrison Formation has not been subdivided in northeastern New Mexico. Details of the lithology, thickness, and areal distribution of the members of the Morrison in northwestern New Mexico are contained in Rapaport and others (1952), Smith (1954), Kelley and Wood (1946), Craig and others (1955), Freeman and Hilpert (1956), Strobell (1956), and Hilpert (1963).

The uranium deposits generally occur in thick gray sandstone beds where these beds contain relatively thin and discontinuous lenses of claystone and abundant carbonized plant debris or fine-grained carbonaceous material. The deposits are generally more or less elongate masses that occur in one or more layers and in belts or trends that are alined with the sedimentary structures of the enclosing host rocks. In the Gallup (locality 3), Smith Lake (locality 4), and Ambrosia Lake (locality 5) districts, the principal deposits are in the Westwater Canyon Member and some are in the overlying Brushy Basin Member. In the Laguna district (locality 6), they are mainly in the Jackpile sandstone (of local usage) in the upper part of the Brushy Basin Member. The principal mines in these deposits are listed in table 29 (Hilpert and Moench, 1960; Granger and others, 1961; Soc. Econ. Geol., 1963). The uranium deposits in the Chuska district (locality 2) are mostly in the Recapture Member and those in the Shiprock district (locality 1) are in the Salt Wash Member (table 29). Only the ores in the Salt Wash contain enough vanadium to be mined for this metal alone or as a coproduct with uranium; they have a U:V ratio of about 1:10.

Outside the six principal districts (localities 1 to 6, inclusive), scattered deposits occur in the Morrison Formation, but they are mostly small; these occurrences include the Westwater Canyon Member in Sandoval County (locality 8; table 29); a sandstone unit at the top of the Brushy Basin Member in Rio Arriba County; unnamed sandstone beds in northwestern Quay County (Griggs, 1955, pp. 192, 195); and one in Harding County (locality 19). A few hundred tons of ore have been mined from the deposits in Sandoval and Harding Counties.

Deposits in rocks of Cretaceous age.—Deposits in rocks of Cretaceous age are generally small and low grade and consist of impregnations of yellow uranium minerals and dark-colored unidentified minerals finely disseminated in carbonaceous sandstone, uraniferous carbonaceous shale, and impure coal (Gabelman, 1956b, 303–319). The most important deposits are in the Dakota Sandstone, from which four properties in the Gallup district (locality 3), five properties in the Ambrosia Lake district (locality 5), and one property in Sandoval County (locality 8) have yielded about 60,000 tons of ore (table 30). The only other productive deposit is the Midnight No. 2 (NW¼ sec. 12, T. 2 N., R. 11 W.) in the Point Lookout Sandstone in Catron County (locality 11), from which some ore has been mined. Other deposits occur, mostly in the Mesaverde Group, in Catron (locality 11), McKinley (locality 5), Sandoval (locality 8), north-central and southwestern San Juan, and western Socorro Counties. Of these, the largest is contained in the La Ventana Tongue of the Cliff House Sandstone at La Ventana Mesa (locality 8), Sandoval County. Here the uranium is in a zone several feet thick that includes three beds: an upper bed, 6 inches to 6 feet thick, of gray sandstone; a middle bed, 2 inches to 4 feet thick, of coal and impure coal; and a lower bed, as much as 10 feet thick, of carbonaceous shale. The middle bed contains the highest grade material (Bachman and others, 1959).

Deposits in rocks of Tertiary and Quaternary(?) age.—Deposits in rocks of Tertiary and Quaternary(?) age are also generally small and low grade. They consist mostly of coatings of carnotite, tyuyamunite, schrockingerite, and meta-autunite in iron-stained carbonaceous sandstone and siltstone. They occur mostly in Catron (locality 11) and northwestern Socorro Counties in the Eocene(?) Baca Formation; in Rio Arriba County along the eastern side of the San Juan Basin in the Paleocene Nacimiento and Eocene San Jose Formations; in eastern Rio Arriba County in the Miocene, Pliocene, and Pleistocene(?) Santa Fe Group; in northeastern San Juan County in the San Jose Formation; in southeastern Sandoval County in the Eocene and Oligocene(?) Galisteo Formation; and in northern Santa Fe County in the Santa Fe Group and in the southern part of the County in the Galisteo Formation. Ore has been mined only from the Red Basin No. 1 (NE¼ sec. 19, T. 2 N., R. 10 W.), which is in a carbonaceous sandstone lens at the base of the Baca Formation (Bachman and others, 1957, pp. 11–12), Catron County (locality 11).

Vein Deposits

Uranium in vein deposits in New Mexico occurs in a wide variety of rock types and structures. These are not an important source of uranium, having yielded only about 15,000 tons of ore through 1963. The ore has come mostly from fault-controlled deposits in sedimentary rocks along the Rio Grande structural trough in Socorro County (localities 12 and 16), and from fissure veins in La Bajada area. Santa Fe County (locality 9), and Grant County (locality 14). Small amounts have been yielded by deposits in brecciated sedimentary and volcanic rocks from Catron (locality 10), Sierra (locality 13), and Hidalgo (locality 15) Counties, and from pegmatites in San Miguel County (locality 21). The vein deposits are summarized by county in table 31.

TABLE 31.—*Uraniferous vein deposits and occurrences in New Mexico.*

Name	Location (section, township, and range, New Mexico Principal Meridian)	Geology	References
Bernalillo County:			
Cerro Colorado-Archuleta	1, 9 N., 1 W. (projected; unsurveyed land).	Yellow uranium minerals in fractures in Tertiary rhyolite dome.	Wright, 1943, pp. 43–46; writer's field notes.
Catron County:			
Baby	20, 10 S., 19 W. (locality 10, fig. 47)	Mineralized fault in Tertiary andesite agglomerate	A. P. Butler, Jr., written communication, September 1964.
Colfax County:			
Blasted Pine	1, 27 N., 25 E	Radioactive vein or fracture in Dakota Sandstone near Tertiary intrusive.	A. P. Butler, Jr., oral communication, September 1964.
Dona Ana County:			
Blue Star	13, 24, 25, 24 S., 3 E. (locality 22, fig. 47).	Uraniferous fluorite in faulted limestone and shale of Magdalena Group.	A. P. Butler, Jr., written communication, September 1964.
Grant County:			
Floyd Collins (probably same as Merry Widow).	21–22, 20 S., 15 W. (locality 14, fig. 47)	Autunite and torbernite occur in quartz-pyrite veins that cut Precambrian granite.	Lovering, 1956; A. P. Butler, Jr., written communication, September 1964.
Inez (7-X-V Ranch)	24, 20 S., 15 W. (locality 14, fig. 47)	Similar to Floyd Collins (above)	A. P. Butler, Jr., written communication, September 1964.
Hines No. 1	34, 21 S., 14 W	Uraniferous fluorite and autunite(?) in quartzite breccia in shatter zone in Cambrian and Ordovician Bliss(?) Sandstone.	Lovering, 1956, pp. 352–353.
Langford	25, 22 S., 16 W	Yellow uranium mineral and uraniferous fluorite in silicified breccia zone in Precambrian granite.	Lovering, 1956, pp. 353–354.
Black Hawk district	21, 18 S., 16 W	Pitchblende occurs in fissure veins in association with various nickel, cobalt, and silver minerals. The veins are principally in the Black Hawk, Good Hope, and Alhambra mines along the southeast side of the Tertiary Twin Peaks monzonite stock.	Gillerman and Whitebread, 1956.
Hidalgo County:			
Napane	25, 29 S., 14 W. (locality 15, fig. 47)	Silicified zone (vein?) in Cretaceous limestone	A. P. Butler, Jr., written communication, September 1964.
Lincoln County:			
Prince	14, 6 S., 11 E	A pyrometasomatic magnetite-hematite replacement of limestone in the Permian Yeso Formation at the margin of the Lone Mountain monzonite stock. The uranium is in unidentified minute particles in the magnetite and in secondary coating in fracture and pore spaces.	Walker and Osterwald, 1956, pp. 213–222.
Silverton	22, 8 S., 15 E	Radioactive brecciated fault zone in Tertiary monzonite	A. P. Butler, Jr., written communication, September 1964.
Luna County:			
Cooks Peak area	12–13(?), 20 S., 9 W	Uranium-bearing fluorite in vein cutting Carboniferous limestone.	Do.
Name unknown	12, 29 S., 11 W	Autunite(?) with iron and copper sulfide in brecciated, silicified, Carboniferous limestone.	Do.

Rio Arriba County:			
Beryl (may be same as the Lonesome deposit).	Possibly NE¼ 1, 26 N., 8 E., or SW¼ 36, 27 N., 8 E.	Samarskite, uraninite, gummite, and monazite occur sparsely with columbite-tantalates in a microcline-quartz pegmatite body.	Just, 1937, p. 67; Jahns, 1946, pp. [illegible].
Pino Verde	NW ¼ 18, 26 N., 9 E.	A microcline-quartz pegmatite dike that contains sparse columbite, samarskite, monazite, and uraninite.	Jahns, 1946, pp. 183–185.
Kiawa	11, 27 N., 8 E.	Samarskite, magnetite, and bismutite occur in fractures in massive quartz in a microcline-quartz pegmatite dike.	Jahns, 1946, pp. 106–115.
North Star	31, 27 N., 9 E.	Similar to Pino Verde (above).	Jahns, 1946, pp. 144–146.
Tusas & JOL	24, 28 N., 7 E., and 18, 28 N., 9 E. (uncertain).	Autunite, torbernite, and sabugalite sparsely disseminated in Precambrian Petaca Schist along walls of purple fluorite veins.	Anonymous file data, probably from AEC.
Sandoval County:			
Mimi No. 4	4, 12 N., 6 E.	Autunite occurs along fractures near base of trachyte sill that intrudes the Mesaverde Group.	G. E. Collins, written communication, May 1955.
Peralta Canyon	9, 17 N., 5 E. (projected; unsurveyed land).	Torbernite and uranophane, associated with copper oxides, coat fracture surfaces and fill open space of brecciated rhyolite.	Jones, 1904, p. 342; Lindgren, Graton, and Gordon, 1910, p. 162.
Santa Fe County:			
La Bajada	9, 15 N., 7 E. (projected, unsurveyed land) (locality 9, fig. 47).	A complex deposit of various metallic sulfides along the brecciated footwall of a limburgite dike in the Tertiary Espinaso of Stearns (1943). Uranium (in unidentified minerals) is disseminated in podlike zones with the sulfides.	Writer's field notes and J. W. Hasler, written communication, October 1955.
Sierra County:			
Pitchblende Strike	26, 10 S., 6 W. (locality 13, fig. 47)	Uraninite and uranophane in brecciated body of chert and limestone (Madera Limestone) enclosed in Tertiary andesite.	Everhart, 1956b, p. 99; A. P. Butler, Jr., written communication, September 1964.
Socorro County:			
Charley No. 2 (Jeter)	35, 3 N., 2 W. (locality 16, fig. 47)	Carnotite, tyuyamunite, autunite, and pitchblende are disseminated in a roughly tabular zone of clayey material and bleached tuffaceous sandstone along the base of the Popotosa Formation where it is in fault contact with underlying Precambrian granite.	Writer's field notes and miscellaneous AEC file data.
Shaft	10, 1 S., 2 W.	Torbernite(?) and carnotite(?) associated with copper carbonates in shear zone in trachyandesite of Tertiary Datil Formation.	Gott and Erickson, 1952, pp. 4 and 13.
Agua Torres	1, 1 S., 2 E. (locality 12, fig. 47)	Fracture fillings of yellow uranium mineral in siliceous limestone breccia on west side of fault that separates the Madera and Abo Formations.	AEC file data.
Marie	12 and 13, 1 S., 2 E. (locality 12, fig. 47)	Similar to Agua Torres (above).	Do.
Carter-Tolliver-Cook	5 and 6, 2 S., 1 W.	Carnotite and uranophane, associated with iron, lead, and copper sulfides occur in mafic dikes that crosscut Precambrian granite and metamorphic rock.	Anonymous file data.
Lucky Don	35, 2 S., 2 E. (locality 12, fig. 47)	Tabular deposit of disseminated carnotite and tyuyamunite in San Andres Limestone in footwall of a fault that separates the Permian San Andres and Yeso Formations.	Writer's field notes.
Little Davie	35, 2 S., 2 E. (locality 12, fig. 47)	Deposit immediately south of, and similar to, Lucky Don (above).	Do.

TABLE 31.—*Uraniferous vein deposits and occurrences in New Mexico*—Continued

Name	Location (section, township, and range, New Mexico Principal Meridian)	Geology	References
Valencia County:			
Woodrow	36, 11 N., 5 W. (locality 6, fig. 47)	Coffinite and other uranium minerals, pyrite, and marcasite impregnate breccia in periphery of a vertical pipe structure in Morrison Formation.	Hilpert and Moench, 1960; Wylie, 1963, pp. 177-181.

RESOURCES

As of January 1, 1963, the U.S. Atomic Energy Commission estimated the uranium reserves in New Mexico to be 32.5 million tons of ore averaging about 0.25 percent U_3O_8 and containing 79,000 tons of U_3O_8.[1] Although more than 2 million tons of ore were mined in 1963, the reserve remained about the same in early 1964 as a result of mine development. This reserve is roughly one-half of the U.S. total ore reserves and enough to sustain a mine yield for 10 to 15 years at the 1963 rate of extraction.

New Mexico's reserves are almost entirely in relatively thick sandstone units in the Westwater Canyon and Brushy Basin Members of the Morrison Formation in the Ambrosia Lake and Laguna districts, McKinley and Valencia Counties. Relatively small reserves are contained in the Todilto Limestone and Dakota Sandstone in these same districts and the remainder is scattered throughout various formations in other parts of the State.

In addition to these ore reserves, an appreciable tonnage of material of submarginal grade occurs on the peripheries of the known ore deposits, especially those in the Ambrosia Lake district. This material has not been thoroughly sampled, and its tonnage has not been calculated, but it probably amounts to several million tons of material averaging 0.1 percent U_3O_8 or a little less. This material cannot be recovered profitably under present economic conditions and may be recoverable only at high cost after the mines are closed.

In contained uranium this peripheral submarginal material may greatly exceed all other submarginal uranium resources in New Mexico, even though many low-grade or submarginal deposits are known in the State (see symbols for "occurrences" on fig. 47). Although an accurate appraisal cannot be made of these occurrences, because exploration and sampling of most of them has not been extensive, none appears to be large. One of the most promising of these is in La Ventana Mesa area, Sandoval County; Bachman and others (1959, p. 307) calculated it contains 132,000 tons of material, 1 foot or more thick, containing at least 0.1 percent uranium, and about 400,000 tons between 0.01 to 0.1 percent uranium.

Most of the potential resources probably occur in the southern San Juan Basin mineral belt.[2] This is a belt of favorable ground defined by numerous sedimentary, structural, and other geologic features which indicate it extends from the vicinity of Gallup eastward to the vicinity of the Rio Grande Valley (Hilpert and Moench. 1959). It is about 80 miles long, roughly 20 to 25 miles wide, and includes the Gallup, Smith Lake, Ambrosia Lake, and Laguna districts. Most of the resources in this belt probably will be found in relatively thick sandstone beds in the Westwater Canyon and Brushy Basin Members of the Morrison Formation. The deposits will generally occur at depths of 1,000 feet or more below the surface, with the depths increasing northward from the outcrop toward the center of the San Juan Basin.

Undiscovered deposits also are likely to occur in the Todilto Limestone where the limestone has been contorted and broken. These

[1] John A. Patterson, address before the National Western Mining Conference, Denver, Colo., Feb. 8, 1963.

[2] Referred to by Kelley and others (1963) as the Grants mineral belt.

deposits may be expected to be small, however, and will occur several hundred feet stratigraphically below the Morrison deposits. Deposits also may occur in the Dakota Sandstone. These also are not likely to be large, but as they occur stratigraphically above the Morrison they may be found and exploited together with the deeper Morrison deposits.

In addition to the potential resources in the southern San Juan mineral belt, a fair potential exists in the eastern parts of the Shiprock and Chuska districts. In the Shiprock district the known deposits are in the Salt Wash Member of the Morrison where this member is relatively thick. The thick part apparently extends eastward into the San Juan Basin, as shown by thickness data and dip directions of sedimentary structures (Craig and others, 1955, figs. 21 and 26). Deposits are expected to occur, therefore, along this eastward projection. They will be found at depths of several hundred feet or more beneath the surface. In the Chuska district, the known deposits occur in the Recapture Member of the Morrison where the member crops out and also is relatively thick (Craig and others, 1955, fig. 22). The sedimentary structures here also indicate an eastward trend (L. C. Craig, written communication, 1962) and, along with the relatively thick sandstone, suggest an eastward projection of favorable ground. The undiscovered deposits in this ground also will occur at depths of several hundred feet or more.

Other potential resources in New Mexico are expected to be relatively small and mostly unimportant from the standpoint of the uranium industry. Many deposits are likely present in sedimentary rocks of Permian, Triassic, and Tertiary ages. Most of them, however, are expected to be small because of the relative thinness of the sandstone and lack of carbonaceous debris in the units. The most favorable units appear to be the Cutler Formation of Permian age, the Agua Zarca Sandstone Member and Poleo Sandstone Lentil, both of Triassic age, along the eastern margin of the San Juan Basin, and the relatively thick sandstone units at the base of the Tertiary Baca Formation, in Catron and Socorro Counties.

The potential for uranium in vein deposits is small. The best potential is probably for deposits in sedimentary rocks associated with faults along the Rio Grande Trough, and in complex fissure veins that contain assemblages of other metals in the White Signal, Black Hawk, and Los Cerrillos districts in Grant, Sierra, and Santa Fe Counties, respectively. Some of these deposits may prove to be profitable as small operations, although their output is not expected to constitute an important part of New Mexico's uranium industry.

VANADIUM

(By R. P. Fischer, U.S. Geological Survey, Denver, Colo.)

The consumption of vanadium in the United States has been increasing gradually, according to figures published by the U.S. Bureau of Mines. Consumption was about 2,000 short tons each year in 1960 and 1961, about 2,300 tons in 1962, and about 2,900 tons in 1963. Of these totals, 75 to 80 percent have gone into special engineering, structural, and tool steels, where it is used as an alloy to control grain size, impart toughness, and inhibit fatigue. The other principal domestic uses have been in nonferrous alloys and chemicals.

The bulk of domestic supplies, and nearly half of the world supply, has come from vanadium-uranium deposits in sandstone in southwestern Colorado and the adjoining parts of Utah, Arizona, and New Mexico. Other principal sources of vanadium include a deposit of vanadium-bearing asphaltite in Peru, vanadate minerals from the oxidized zones of some base-metal deposits in Africa, and vanadium-bearing iron deposits in Europe and Africa. These and similar iron deposits in many parts of the world contain very large resources of vanadium. Probably they will become increasingly important as sources of vanadium in the future.

Of these four principal types of commercial vanadium deposits, only two are known in New Mexico, vanadium-uranium deposits in sandstone and vanadate deposits with base metals. Each type has yielded a small amount of vanadium, but the exact amount has not been reported in publication. Known occurrences of these types are shown on figure 47, which also shows uranium occurrences in New Mexico.

Uranium deposits in sandstone are numerous in northwestern New Mexico (fig. 47), and some of those in McKinley and Valencia Counties are large, yielding important amounts of uranium ore. The average vanadium content of most of these deposits, however, is only a few tenths of 1 percent V_2O_5 or less, which is too low to make its recovery profitable, although a little vanadium has been recovered in processing some uranium concentrates. One group of deposits (No. 1, fig. 47) along the Arizona State line in northwestern San Juan County, on the other hand, yields ore containing more than 1 percent V_2O_5. During World War II these deposits were mined for vanadium alone, and since the late 1940's they have been mined for both vanadium and uranium. Ore production from these deposits, however, has been relatively small.

The total content of vanadium in the known sandstone-type deposits in New Mexico amounts to many thousands of tons. Because of the low vanadium content in most of these deposits, however, very little of this metal can be recovered profitably unless economic or technologic factors change to favor vanadium. The geology of these deposits is described in the section on uranium in this report.

Crystals of lead, zinc, and copper vanadates are common in the oxidized zones of base-metal deposits in areas of arid or semiarid climates in many parts of the world. Generally these crystals are irregularly scattered in the oxidized zones, though in places they are concentrated in patches or bodies from which some material of commercial grade can be obtained by selective mining. In Southwestern United States, vanadate minerals occur in many deposits but only a few of these have yielded commercial vanadium ore.

Vanadate minerals have been reported in at least 14 mining districts in New Mexico (fig. 47), but production has been reported only from locality a, the North Magdalena district (Lasky, 1932), Socorro County: locality b, Hall mine, Hillsboro district (Lindgren and others, 1910; Anderson, 1957) and locality c, Caballo Mountains district (Hess, 1912; Lasky and Wootton, 1933; Kelley and Silver, 1952), Sierra County; and locality d, Lucky Bill mine, Central district

(Larsh, 1913; Lasky and Wootton, 1933; Lasky, 1936), Grant County. None of these are credited with a sustained vanadium output, however, so the yield is assumed to be small. Data for a quantitative resource appraisal are not available, but no significant production of vanadium is likely from any of the known deposits.

SELENIUM AND TELLURIUM

(By D. F. Davidson and H. C. Granger, U.S. Geological Survey, Denver, Colo.)

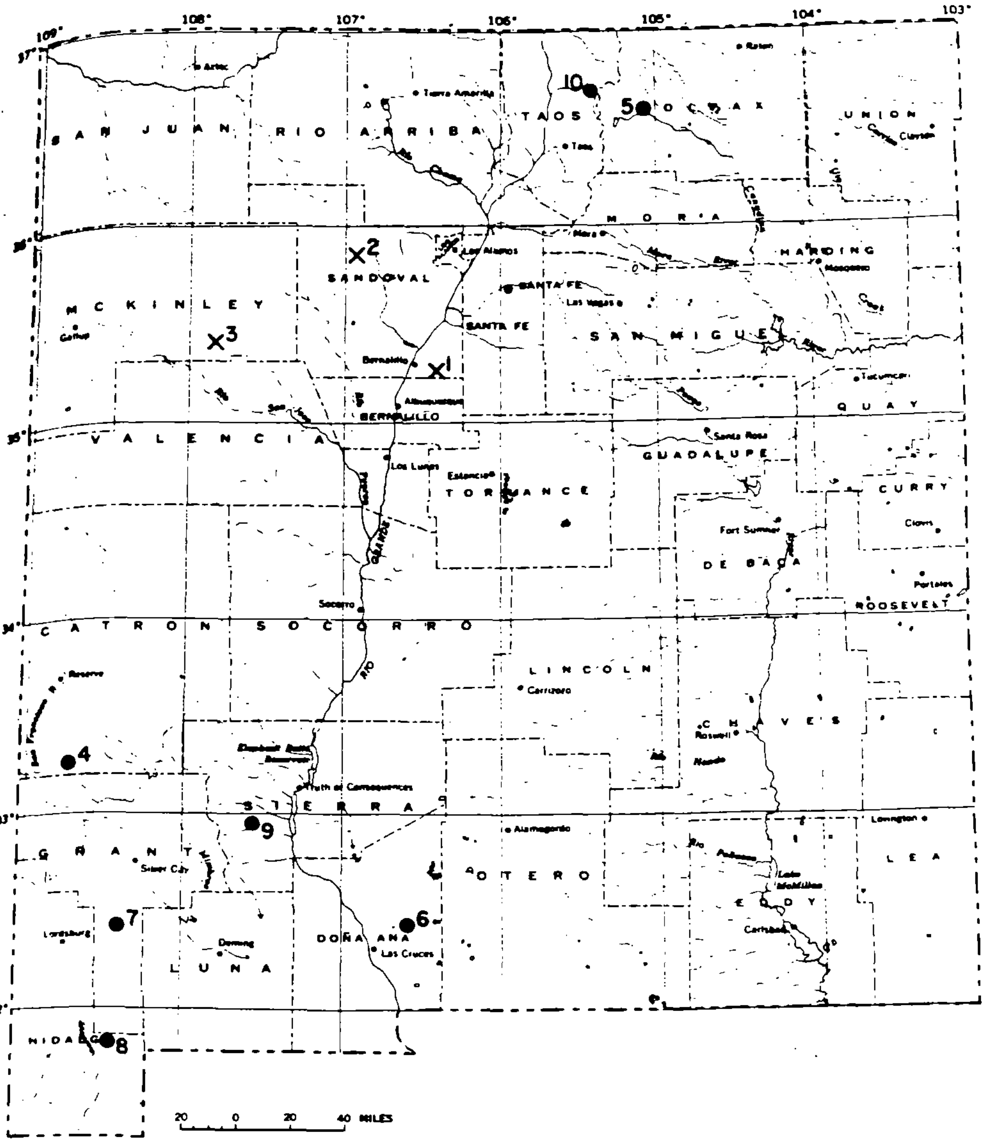
SELENIUM

Selenium is an allotropic element that is widely distributed in small quantities in the earth's crust. Where chemically pure, it may have the form of brick-red amorphous powder, a gray metallic crystalline mass, or red crystals. Selenium can act as either metal or nonmetal, electrical conductor or insulator, hydrogenator or dehydrogenator, colorant or decolorizer. It is toxic and is the only element that is often present in healthy plants in large enough quantities to be lethal to grazing animals.

High-purity selenium is used chiefly in electronic applications; commercial-grade selenium is consumed by the chemical, rubber, metallurgical, ceramic, and glass industries. Anode slime from electrolytic refining of copper is the principal commercial source of selenium, but lesser quantities are recovered from lead smelter flue dusts.

Most commonly, selenium is combined in sulfide or selenide minerals associated with copper, uranium, silver, antimony, and other metals; it occurs infrequently in the native state. No ores are mined exclusively for selenium. Selenium is known to occur in two principal kinds of deposits in New Mexico: (1) with uranium in sandstone deposits in the Ambrosia Lake or Grants district, Valencia County, and (2) in very low concentrations with uraniferous coal or coaly materials in the Hagen and La Ventana district, Sandoval County (fig. 48).

The selenium that occurs with the uranium ores being mined in the Grants uranium district may represent a future source of the element. The iron diselenide mineral, ferroselite, and gray native selenium have been identified but much of the selenium may occur in forms not yet recognized. Typical uranium ores from the Grants district contain 10 to 50 parts per million selenium. Local concentrations, particularly at the interface between oxidized and unoxidized host rock, may contain from several hundred parts per million to several tenths of a percent selenium. Because many million tons of uranium ore will be mined from the Grants uranium district by 1970 several hundred tons of selenium will have passed through the uranium mills. It has been generally conceded, however, that the overall grade of the selenium is too low to recover economically, and large-scale mining of the uranium does not permit selective mining of the selenium concentrations. Because of tendency of the selenium to move under oxidizing conditions and to be reconcentrated under reducing conditions in the vicinity of the ore deposits, it is possible that parts of the tailings piles from the uranium mills may become selenium ore deposits after long exposure to weathering.



EXPLANATION

×

Selenium occurrences
1. Hagan district
2. La Ventana district
3. Ambrosia Lake district

●

Tellurium occurrences
4. Wilcox district
5. Ute Creek district
6. Organ district
7. Little Burro Mountain district
8. Sylvanite district
9. Hillsboro district
10. Red River district

FIGURE 48.—Selenium and tellurium in New Mexico.

TELLURIUM

Tellurium is a toxic tin-white element that resembles antimony in appearance and is related to sulfur and selenium. It is neither as widespread nor as often concentrated as sulfur or selenium. It occurs in the native state and in more than 40 minerals, none of which is processed solely for the element. The tellurium of commerce is recovered as a byproduct during the refining of copper and lead ores. Only small quantities of tellurium are required for most of its applications in the ceramic, chemical, metallurgical, and rubber industries; it has been substituted satisfactorily for selenium in some applications when that element was in short supply. The future of tellurium is uncertain. It is potentially useful in thermoelements which convert heat from solar energy or other sources to electricity, and may become increasingly important in space travel.

Tellurium has been found in at least seven mining district in New Mexico, associated with gold deposits (fig. 48). Tellurium or tellurium minerals have been described from the Wilcox district, Catron County; Ute Creek, Colfax County; Organ district, Dona Ana County; Little Bruno Mountain, Grant County; Sylvanite, Hidalgo County; Hillsboro, Sierra County; and Red River, Taos County. Only one occurrence, at the Lone Pine mine, Wilcox district, has been explored as a possible source of tellurium; there, at least 5 tons of high-grade tellurium "ore" have been produced since the early 1930's.

THORIUM

(By M. H. Staatz, U.S. Geological Survey, Denver, Colo.)

Thorium is a silver-gray metal that, like uranium, is the parent of a series of radioactive decay products ending in a stable isotope of lead. Because of this characteristic, thorium is a potential source of atomic power. Thorium, however, unlike uranium, does not contain a fissionable isotope to start the reaction. The uranium isotope U^{235}, the only naturally occurring fissionable material, must be added. Once the reaction has begun, neutrons resulting from the U^{235} fissions will convert the thorium into U^{233} (Kelly, 1962, pp. 24–25). The use of thorium for nuclear energy is in the experimental stage and is in competition with relatively cheap and abundant uranium. By 1961, the U.S. Atomic Energy Commission had built or committed for construction five different types of reactors to study the use of thorium as a nuclear fuel (Baker and Tucker, 1962, p. 1211). The first commercial nuclear plant to use thorium as a fuel became operative in August of 1962 (Parker, 1963, p. 1199). Thorium also has a number of industrial uses. Over 90 percent of the thorium used in the United States goes into gas mantles and thorium-magnesium alloys. Minor amounts of thorium are also used in refractories, polishing compounds, chemicals, drugs, and electronic products. Experimental work has been carried out on thorium-nickel alloys.

Thorium occurs in a large number of minerals, but only a few of these have been found in sufficient concentrations to be used as ores. In many minerals it is associated with the rare earth elements. The most important source mineral for thorium in the world is monazite, a phosphate of the cerium group rare earths. The thorium content of this mineral is variable, but commercial monazite contains between 3 to 10 percent thorium oxide (ThO_2) and 55 to 60 percent combined rare earth oxides (Kelly, 1962, p. 5). Monazite is found in pegmatites, granites, syenites, carbonatites, veins, metamorphic rocks, and in recent and fossil placers. Other potential sources of thorium are the minerals thorite and thorogummite, and multiple-oxide minerals such as euxenite, samarskite, and fergusonite. Thorite and thorogummite are found in veins and pegmatites. The multiple-oxide minerals occur in pegmatites and in placers derived from pegmatites.

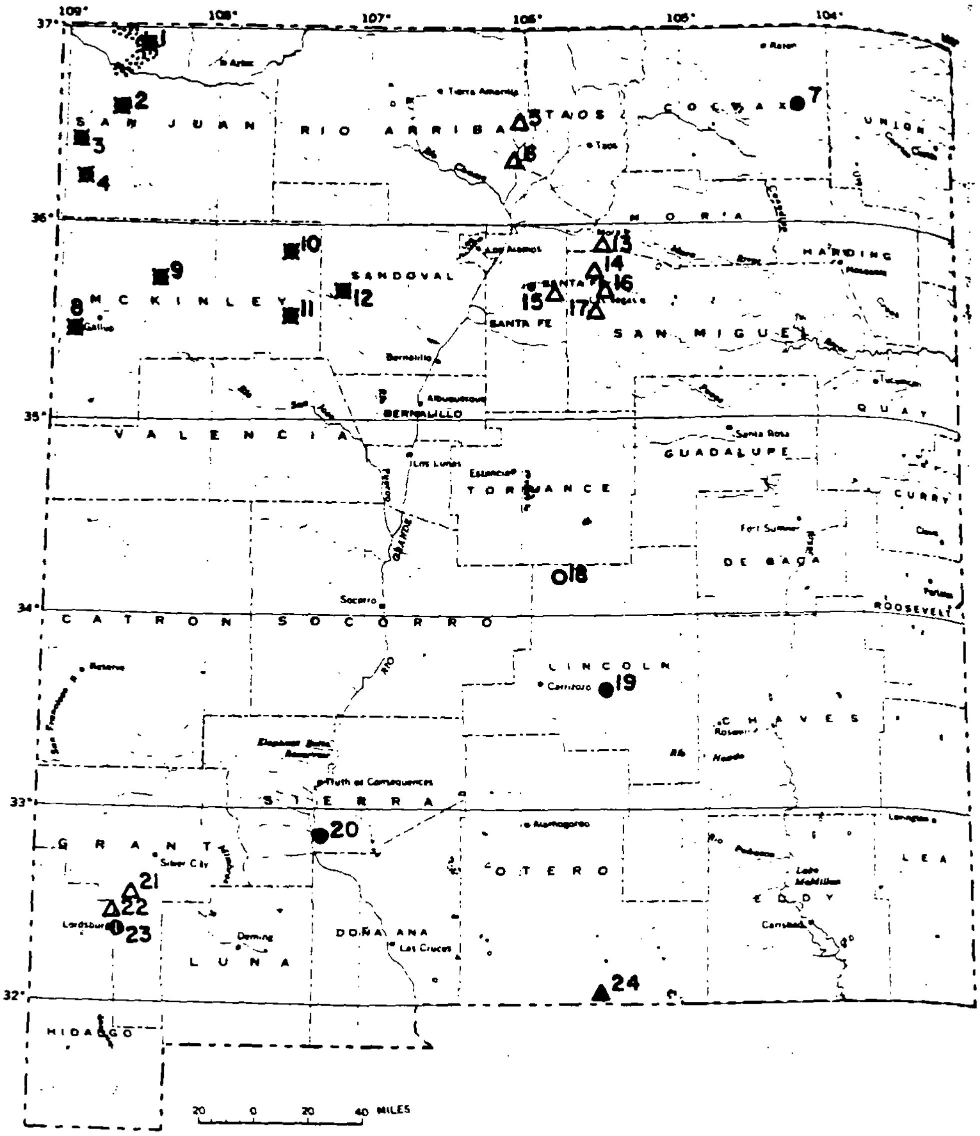
The present thorium requirements of the United States are small compared to many other metals. In 1961 only 121 tons of ThO_2 were used in this country (Baker and Tucker, 1962, p. 1210). Most of the ThO_2 used in the United States in 1962 was derived from Canadian uranium sludges and from South Africa's Vanrhynsdorp monazite lode (Parker, 1963, p. 1200). Some monazite has also come in recent years from placer deposits in North Carolina, Florida, and Idaho.

Although thorium deposits are known in a number of places in New Mexico, to date no thorium has been produced. The known New Mexico deposits are either smaller or of lower grade than similar deposits in other States. Furthermore, the marketing of thorium ores is difficult throughout the United States because there is no established market comparable to those for the more widely used metals and the prices of the ores are generally determined by negotiation between buyer and seller. Detailed information on economic factors bearing upon thorium, is given in a recent publication by the U.S. Bureau of Mines (Kelly, 1962).

In New Mexico thorium has been found in veins, pegmatites, and fossil and recent placers. Thorium-bearing veins are found in four parts of the State (Nos. 7, 19, 20, and 23, fig. 49). The most northern of these is in the Chico Hills (No. 7), where at least seven veins ranging from a fraction of an inch to 15 feet in width have been found in irregularly brecciated zones in Dakota sandstone and in phonolite. Their exposed length is from 10 to 550 feet. Vein material consists principally of quartz, iron-oxide minerals, thorite, plumbogummite, and brockite; brockite is the principal thorium mineral. A number of the veins averages 0.3 percent thorium oxide.

The second locality occurs in the Capitan Mountains (No. 19), where a number of irregular veins, similar to those in the Chico Hills, occur in brecciated fine-grained granite. Their thickness is extremely irregular, ranging from less than an inch to 8 feet. Most can be traced for distances of less than 100 feet. Thorite is the principal thorium mineral. Grade is highly irregular and may vary from a few hundredths to several percent thorium oxide within a few feet along the vein.

The third locality is at the southern end of the Caballos Mountains (No. 20), where scattered veins of orangish-red feldspar which cut granite of Precambrian age contain thorite, iron-oxide minerals, and rutile. A yellow uranium mineral and the rare earth mineral, bastnaesite, are also found in one of the veins. These veins are from a few inches to several feet wide and as much as several hundred feet long. Thorium content is erratic and some veins contain only a few hundredths of a percent of thorium oxide; others as much as 0.5 percent.



EXPLANATION

Fossil beach placer

Fossil beach placer district covering broad area

△
Granitic pegmatite or group of pegmatites

▲
Alkalic pegmatites

●
Veins containing thorium

○
Veins containing rare earths

DEPOSITS

1. Shiprock group
2. Chaco River
3. Sanostee
4. Toadlena
5. Petaca district
6. Ojo Caliente district
7. Chico Hills
8. Defiance
9. Standing Rock
10. Star Lake
11. Miguel Creek dome
12. Arroyo Torreon area
13. Pidlite pegmatite
14. Elk Mountain district
15. Dalton Creek
16. Sparks-Stone pegmatite
17. Bull Creek
18. Gallinas Mountains district
19. Capitan Mountains
20. Caballo Mountains
21. High Noon pegmatite
22. Gold Hill district
23. Grandview
24. Wind Mountain

FIGURE 49.—Thorium and rare earths in New Mexico.

The fourth locality is near the Gold Hill area (No. 23), where two small areas in a basalt dike have been weakly mineralized. These two areas have small veins containing thorite. Grade of this rock is less than 0.1 percent thorium oxide.

Pegmatites containing thorium minerals are found in the north-central and southwestern parts of New Mexico (fig. 49). Thorium has been reported in these areas in one or more of the following minerals: monazite, samarskite, euxenite, fergusonite, and allanite (Olson and Adams, 1962; Jahns, 1946; Jahns, 1953, p. 1090; Northrop, 1944, p. 220; Anderson, 1957, p. 119). Monazite and samarskite are the most common. The thorium minerals are generally erratically scattered through a narrow zone in the pegmatite and are too sparse to serve as a source of thorium, although crystals of monazite and samarskite from the Petaca district (No. 5) have been sold to museums.

Recent placers are the principal source of thorium minerals in most regions; however, in New Mexico only trace amounts of thorium minerals have been found in such deposits. Thirty-five fossil placers, mainly sandstones, contain monazite in northwestern New Mexico (fig. 49). Twenty-seven of these fossil deposits are found in a zone northeast of Shiprock (No. 1). They represent consolidated beach sands containing various heavy minerals that were concentrated by waves and currents along an ancient beach (Dow and Batty, 1961, p. 3). All the deposits occur in sandstones of Late Cretaceous age. The fossil placers are lenticular or crescent shaped and generally not continuous. They range from about 50 to 7,300 feet long, 30 to 800 feet wide, and a half to 14 feet thick (Chenoweth, 1957, p. 213; Dow and Batty, 1961, pp. 34–40). Heavy minerals make up 50 to 60 percent of these sandstones and consist of ilmenite, leucoxene, zircon, and garnet, with minor amounts of monazite, rutile, spinel, epidote, magnetite, and tourmaline. New Mexico deposits contain an estimated 4,751,000 tons of titaniferous sandstone having a weighted average of 0.1 percent equivalent thorium oxide, 12.8 percent titanium oxide, 15.5 percent iron, and 2.1 percent zirconium oxide (Dow and Batty, 1961, p. 45). The greater part of these resources is concentrated in a deposit near Sanostee (No. 3), which is 7,300 feet long, 200 to 800 feet wide, and 1 to 14 feet thick. It has an average grade of 0.12 percent equivalent thorium oxide, or twice the grade of the next richest deposit (Dow and Batty, 1961, p. 40). A detailed description of this deposit is given by Bingler (1963).

Thorium deposits of New Mexico are not likely to be mined in the near future. In part this is due to the small demand for the element and to present competition from more cheaply mined foreign ores. In part this is also due to the small size and low grade of most of the known deposits. Present uses do not favor an increased demand in the immediate future, but the possibility of increased use of thorium as a source of power in atomic reactors or in some of the new special-use alloys now being developed suggest an increase in the not too distant future. Additional uses will depend on advances in technology, which may result from current and projected research. The largest tonnage of thorium known in the State is in the fossil placer deposit near Sanostee. This placer is primarily a titanium property from which a thorium concentrate could be produced as a byproduct. The long distances to markets, however, do not favor operation of this placer in the immediate future. The known vein deposits are too small and the thorium is too erratically distributed to compete in the near future with bigger and richer vein deposits in Idaho and Colorado.

Possible exploratory targets for thorium in New Mexico include veins that are larger and higher in grade than those now known. Vein deposits are commonly found near alkalic rocks, such as syenite and phonolite, and areas surrounding this type of rock, as in the Gallinas Mountains in Lincoln County or in the Cornudas Mountains in Otero County, should be examined first. Further exploration for larger deposits might also be carried out in the Chico Hills (No. 7) and the Capitan Mountains (No. 19).

RARE EARTHS

(By J. W. Adams, U.S. Geological Survey, Denver, Colo.)

The rare earth metals comprise the 15 elements having atomic Nos. 57 to 71, including lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). One of these, promethium, is not known to occur in nature. Yttrium (Y), with atomic No. 39, is also classed with the rare earths because of its chemical similarities and geochemical affinities.

The first seven elements listed above (La through Eu) are included in the cerium group of rare earths, so-called because cerium is their most abundant member. The remaining eight elements (Gd through Lu) together with yttrium are called the yttrium group. The two groups are also referred to, respectively, as the "light" and "heavy" rare earths. The properties of the members of the two groups of rare earths are sufficiently distinct to cause one group to predominate over the other in most minerals where they occur, even though all or nearly all are ordinarily present (Olson and Adams, 1962).

The rare earths have many industrial applications such as in the steel industry, nonferrous alloys, glass manufacture and glass polishing, sparking alloys, and carbon electrodes for arc light and projection lamps. Rare earth requirements are, however, relatively small compared to many other metals: domestic consumption in 1958 being only about 1,600 short tons of rare earth oxides (Baroch, 1960, p. 687). The rare earth industry is developed almost entirely around the cerium group elements, primarily cerium, lanthanum, praseodymium, and neodymium. Although considerable research is being directed toward finding uses for yttrium and the heavy rare earth elements the current demand for them is small.

The rare earths are found in a large number of minerals, but only a few of these have been found in sufficient concentration to be used as ores. The most widely used source mineral is monazite, a rare earth phosphate, but deposits of bastnaesite, a rare earth fluorcarbonate, are found in New Mexico. Bastnaesite is currently being mined at Mountain Pass, Calif. Both monazite and bastnaesite contain dominantly cerium group elements.

Commercial monazite commonly contains 55 to 60 percent combined rare earth oxides and between 3 to 10 percent thorium oxide (Kelly, 1962, p. 5). Monazite is not only the principal ore mineral of rare earths, but the principal one of thorium (see "Thorium" chapter) as well. Bastnaesite has a slightly higher rare earth content than does monazite, but contains little or no thorium.

Minerals in which the yttrium group elements predominate include xenotime, and yttrium phosphate, and euxenite, a multiple oxide of yttrium, niobium, and titanium.

The marketing of rare earth ores is difficult as there is no established market comparable to that of the more widely used metals, and prices are generally determined by negotiation between buyer and seller. Detailed information on the economics of rare earths is given in a recent publication of the U.S. Bureau of Mines (Kelly, 1962).

Rare-earth-bearing minerals have been found at a large number of localities in New Mexico (fig. 49) in several different geologic environments, including vein deposits, pegmatites, and ancient placers. The most important rare earth deposits are in the Gallinas Mountains in Lincoln County (No. 18), where bastnaesite occurs in fluorite- and fluorite-copper-bearing veins and breccia fillings. The rare earth mineral was discovered in 1943 during an investigation of the fluorspar potential of the district by the U.S. Bureau of Mines and the U.S. Geological Survey (Glass and Smalley, 1945; Soulé, 1946), and although the deposits appear to be quite small, their rare earth potential is not known.

The deposits in which the bastnaesite occurs are largely confined to the Yeso sandstone and appear to be genetically related to younger alkalic rocks that are intrusive in the area (Perhac and Heinrich, 1964). The location of most of the deposits is shown on the geologic map of the area by Kelley (1947).

In the Gallinas district, bastnaesite occurs as small yellow crystals in vein material that is commonly rich in fluorite but which may contain barite, quartz, calcite, pyrite, copper sulfides, galena, and supergene minerals such as limonite. Very little thorium is present in the bastnaesite, and the radioactivity of the vein material is slight. The best known occurrence is at the Red Cloud mine, where a 1,400-pound sample of fluorspar ore from the Red Cloud mine contained 3.2 percent total rare earth oxides (Soulé, 1946, p. 21), which would represent nearly 5 percent bastnaesite. Locally the bastnaesite may be much more abundant, and Soulé (1946, p. 7) noted that in the Red Cloud mine it occurred well beyond the limits of the better grade florspar ore. Bastnaesite has been found in most of the fluorite and fluorite-copper deposits in the Gallinas area (Perhac and Heinrich, 1964, p. 231). The bastnaesite content of the various deposits has not been determined, but from modal analyses of high-grade specimens (Perhac and Heinrich, 1964, p. 231) it would appear that most of the veins contain less than 5 percent.

During the period 1954–56, approximately 71 tons of bastnaesite concentrate were produced, most of which came from the Red Cloud (Conqueror No. 9) mine (Griswold, 1959, p. 64). No further production of rare earth ores has been reported from the Gallinas district, probably because the limited market for bastnaesite is adequately supplied by the very large deposit at Mountain Pass, Calif.

Rare earths have been found in other vein-type deposits in New Mexico, notably those in the Chico Hills, Colfax County (No. 7); in the Capitan Mountains, Lincoln County (No. 19); and in the Caballo

Mountains, Sierra County (No. 20) where bastnaesite occurs in at least one radioactive deposit (see "Thorium" chapter).

Pegmatite is a type of igneous rock generally considered to represent the crystallization product of residual magmatic fluids (see "Pegmatite" chapter) and as such may contain concentrations of a number of rare elements whose properties inhibited their entry into the minerals of earlier formed rocks. The rare earths are among these elements and appear in pegmatites as the major constituent in a number of minerals as well as a minor constituent of several others.

Rare earth minerals occur in a large number of granitic pegmatites in New Mexico. Most of these deposits are in north-central New Mexico, chiefly in the Petaca and Ojo Caliente districts (Nos. 5 and 6) in Rio Arriba County (Jahns, 1946; Redmon, 1961) and along the east side of the Sangre de Cristo Mountains (Nos. 13, 14, 15, 16, and 17) in the southern part of Mora County and the northern part of San Miguel County (Jahns, 1946; Jahns, 1953; Redmon, 1961). Rare earth-bearing pegmatites are also found in the Gold Hill area (No. 22) in Hidalgo County, and in the White Signal district (No. 21) in Grant County.

Monazite is the most abundant rare earth mineral in the pegmatites of north-central New Mexico. It is commonly in small tabular tan to brick-red crystals, and is appreciably radioactive due to contained thorium. Individual crystals and masses weighing as much as 10 pounds have been found in the Petaca district (Northrop, 1959, p. 359). In addition to monazite, several of the multiple-oxide-type rare earth minerals, such as samarskite, fergusonite, euxenite, and betafite have been reported (Northrop, 1959). Minerals of this group contain varying amounts of rare earth elements, together with niobium, tantalum, titanium, iron, thorium, and uranium; are commonly dark brown to black; have a glassy luster; and are highly radioactive. Identification of individual species is difficult and commonly requires X-ray analysis.

The beryllium-bearing rare earth silicate, gadolinite, has been noted by Jahns (1946, p. 285) in pegmatites in the Elk Mountain district (No. 14).

Pegmatites in the Gold Hill area in Hidalgo County (No. 22) are reported to contain the rare-earth-bearing silicate, allanite, as well as euxenite, samarskite, and cyrtolite, a variety of zircon in which the rare earths are important constituents. Euxenite has been found also in a pegmatite on the High Noon No. 1 claim in the White Signal district (No. 21) in Grant County (Olson and Adams, 1962).

There has been no significant production of rare earth minerals from granitic pegmatites in New Mexico, although some monazite has been recovered as a byproduct of mica mining in the Petaca and Elk Mountain districts (Jahns, 1946, p. 99; Redmon, 1961, p. 74).

Alkalic pegmatite dikes along the margin of the nepheline syenite laccolith of Wind Mountain in Otero County (No. 24) contain minor amounts of rare earths in the zirconium silicate, eudialite (Warner and others, 1959, pp. 137–138). Although this occurrence is in itself of little economic importance, the alkalic intrusive area of the Cornudas Mountains, of which Wind Mountain is a part, is a favorable environment for other rare earth deposits.

No important modern placer deposits of rare earth minerals have been reported in New Mexico, but there are many known occurrences

Ancient monazite-bearing placers in sandstones of Late Cretaceous age in northwestern New Mexico (Nos. 1, 2, 3, 4, 8, 9, 11, 12, and 16). These fossil placers represent accumulations of heavy minerals along beaches of ancient regressive seas (Chenoweth, 1957, pp. 212–217), and, like modern beach deposits, they are narrow, lenticular sandbodies that follow the trend of the ancient shoreline. Some deposits, however, may be several thousand feet in length and several hundreds of feet in width and contain large tonnages of rock composed chiefly of quartz, feldspar, ilmenite, magnetite, leucoxene, zircon, and monazite cemented by ferric iron and carfonate minerals. The rock is characteristically dark in color and shows anomalous radioactivity, partly due to the thorium in the monazite. The fossil placer deposits have been explored chiefly for their titanium potential (Dow and Batty, 1961) and are estimated to contain nearly 5 million tons of rock with a weighted average of 0.10 percent equivalent thorium oxide.

TIN

(By C. L. Sainsbury, U.S. Geological Survey, Denver, Colo., and R. H. Jahns, the Pennsylvania State University, University Park, Pa.)

Tin has been used by civilized peoples at least since the late bronze age (3500–3200 B.C.), and today it remains a strategic commodity of which the United States has little. The metal has two modifications: "white" tin of tetragonal symmetry and specific gravity 7.31, and "gray" tin of cubic symmetry and specific gravity 5.75 (Lange, 1961). At low temperatures (below 13.2° C.), the white tin changes to gray tin, which crumbles to a powdery mass. Alloying tin with any other metal prevents the change from white to gray tin. Toward air, water, and weak acids and bases, tin is chemically resistant because of the formation of a tin oxide coating. This inertness, along with its extremely low surface tension in the molten state, which allows it to build very thin coatings on other metals, leads to its main use as tinplate. Other major uses are as alloys in bearing metal and in solder, bronze, and brass.

Although the United States consumes more than 54,000 long tons of primary tin metal yearly (1962), it produces only a few tons, most of which comes from small tin deposits in Alaska and as a byproduct of molybdenum mining in Colorado. Of greater significance is the fact that total known U.S. resources of possible economic grade are but a small percentage of 1 year's consumption. Hence, every domestic tin deposit is of great interest, although this interest is tempered by the fact that tin has been easy to obtain on a worldwide basis, and, in fact, has often been in excess supply. The major tin-producing countries are Malaya, Indonesia, Bolivia, Republic of the Congo, and Nigeria, listed in decreasing importance.

In New Mexico, three different types of deposits that contain tin as a significant metallic constituent occur in well-defined areas, each of which includes more than one deposit. In spite of substantial exploration, however, no commercially important lode deposits have been found, and placer deposits have yielded concentrates equivalent to only a few tons of tin metal. Distribution of tin deposits in New Mexico is shown on figure 50.